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The Effects of Discharges from Limestone Quarries on Water Quality and Aquatic Biota

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Washington, DC

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Agency

Effluent Guidelines Division
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June 1982

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Water and Waste Management

EPA

Report to Congress

The Effects of Discharges from Limestone Quarries on Water Quality and Aquatic Biota

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16. ABSTRACT

This report documents the procedures, wastewater analysis results, water quality effects and biological effects of limestone quarring and processing operations on surface streams. Data was gathered by on site sampling of process steams (treated and untreated) at nine limestone operations and biological sampling of the receiving streams. Published data was gathered on the genral effects of constitutents present in wastewater streams and effects of limestone effuents are evaluated on information from the literature and sampling.

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THE EFFECTS OF DISCHARGES FROM LIMESTONE QUARRIES ON WATER QUALITY AND AQUATIC BIOTA

A REPORT TO THE
CONGRESS OF THE UNITED STATES

Prepared by:

U. S. Environmental Protection Agency
Effluent Guidelines Division
Washington, D. C.

June 1982

NOTICE

This report has been reviewed by the Effluent Guidelines Division, Office of Water, U.S. Environmental Protection Agency and approved for publication. Mention of trade names or commercial products does not constitute endorsement or recommendation for use.

UNITED STATES ENVIRONMENTAL PROTECTION AGENCY
WASHINGTON, D.C. 20460

JUN 15 1982

THE ADMINISTRATOR

Honorable George Bush
President of the Senate
Washington, D. C. 20510

Dear Mr. President:

I am pleased to submit the enclosed report entitled "The Effects of Discharges from Limestone Quarries on Water Quality and Aquatic Biota." This report is being forwarded to you in response to a request from the Senate Committee on Environment and Public Works during its discussion on the Clean Water Act Amendments of 1977. (Senate Report No. 95-370 page 83).

This report presents the results of extensive data collection efforts that included literature searches, sampling for biological effects, and water quality sampling and analysis. Included in the report is an evaluation of wastewater treatment technology and a cost analysis.

The results of this study indicate that wastewater which has been treated to remove suspended solids causes minimal adverse effects on ambient water quality. However, untreated wastewater from this industry, in spite of the beneficial effects due to its chemical composition, can cause substantial adverse physical effects which are due to siltation.

I hope that this report will be useful to you in development of any future policy or legislation affecting the limestone mining industry. I appreciate this opportunity to be of service to you.

Sincerely yours,

Anne M. Gorsuch

Enclosure

UNITED STATES ENVIRONMENTAL PROTECTION AGENCY
WASHINGTON, D.C. 20460

JUN 15 1982

THE ADMINISTRATOR

Honorable Thomas P. O'Neill, Jr.
Speaker of the House of Representatives
Washington, D.C. 20515

Dear Mr. Speaker:

I am pleased to submit the enclosed report entitled "The Effects of Discharges from Limestone Quarries on Water Quality and Aquatic Biota." This report is being forwarded to you in response to a request from the House Committee on Public Works and Transportation during its discussion on the Clean Water Act Amendments of 1977. (Congressional Record, H12938, December 15, 1977).

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Enclosure

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Obviously all the quarry owners and operators provided the vital input to the study, the quarries for field sampling. The authors appreciate the efforts of Jess Wright of Fort Calhoun Stone Co., Tom Scott of River Products Co., Rick Cole of Flinkote Stone Products, Mike Staudohar of France Stone Co., Ernie Riggs of Southern Stone, Robert Blaker of Oldham County Stone Co., Don Connell of The Stone Man, Inc., and Jay Brown of Kentucky Stone Co.

The National Crushed Stone Association, Portland Cement Association, and National Limestone Institute provided consultation on treatment cost data and possible quarry visit sites.

Project Officer for this study was Ron Kirby, U.S. Environmental Protection Agency, Effluent Guidelines Division.

1.0 SUMMARY

This report documents the procedures, analysis results, and conclusions of a study to identify the effects of limestone quarrying and processing operations on water quality and aquatic biota.

Data was gathered both from the literature and by sampling various process streams and discharge receiving streams at nine different limestone quarries. Published data was gathered on the effects of constituents typically present in discharges from limestone operations on water quality and aquatic biota. Field sampling was conducted at quarries in Nebraska, Iowa, Michigan, Ohio, Kentucky, Tennessee, Alabama, and Maryland. The sampling was done to confirm the levels of total suspended solids, dissolved solids, hardness, pH, silica, turbidity, lead, mercury, nickel, chromium, cadmium, selenium, zinc, iron and asbestos in limestone operation process waters and discharges. In addition, the receiving streams were analyzed by biologists for effects on aquatic biota of limestone operation discharges.

Water samples were taken at various points within the limestone facilities to assess the effectiveness of treatment methods used.

It was found that:

- wastewater treatment by use of sedimentation ponds which are standard practice for this industry remove a significant portion of the pollutants in the untreated process water and mine water when properly operated,
- treated effluents have a minimum impact on water quality and aquatic biota,

- washwater discharged without treatment could have a significant effect on water quality and aquatic biota,

2.0 CONCLUSIONS

The following conclusions can be drawn from this study:

- Simple wastewater treatment techniques (i.e. sedimentation ponds) are very effective in reducing levels of pollutants in effluent discharges from limestone quarrying and processing operations. Most operations employ this method of treatment.

- Levels of total suspended solids (TSS) in treated effluents should cause little impact to water quality or aquatic biota.

- Levels of TSS in untreated washwater could adversely affect water users and most forms of aquatic biota if discharged without treatment.

- Treatment for pH control of effluent discharges from limestone quarries is seldom, if ever, required to meet water quality standards.

- Trace elements (lead, mercury, nickel, chromium, cadmium, selenium, zinc, and iron) are present at low or below detectable levels in effluent discharges from limestone operations. These levels are contained primarily in the solids. Treatment to remove suspended solids will also remove some metals.

- Asbestos fibers at low or natural background levels are found in discharges from some limestone operations. Treatment to remove suspended solids will also be a control and remove some asbestos.

- Modifications to operation management practices at some quarries could reduce impacts on receiving streams. In some cases the TSS level at the confluence of effluent stream and the receiving stream is an order of magnitude higher than the TSS level of the treated effluent.

- No limestone operations were identified that were forced to close because of increased cost of operation resulting from regulatory compliance during the time effluent regulations were in effect.

3.0 INTRODUCTION AND BACKGROUND

The Environmental Protection Agency promulgated final effluent guidelines for the crushed stone subcategory within the mining and mineral processing industry on July 12, 1977 (FR, July 12, 1977, Vol. 42, No. 133). Limestone quarrying and processing operations were included in this subcategory. Following the promulgation of these guidelines, representatives of the crushed stone industry challenged the guidelines. The Fourth Circuit Court of Appeals remanded the guidelines on June 18, 1979. (National Crushed Stone Association v. EPA, 13 ERC 1277). In 1977, Congress during its discussion on the Clean Water Act Amendments requested that EPA conduct a study to consider the effect of limestone quarrying operations on water quality. Radian Corporation was chosen to conduct the study, and work was begun in the Fall of 1979. The study consisted of a literature survey and field sampling to gather data on the types and quantities of constituents present in limestone discharges, and their effects on water quality and aquatic biota.

Ten field surveys were planned and conducted at limestone operations that provided a random geographical distribution among limestone producing areas. It was desired that these visits be made to medium to large size (production) plants with and without limestone washing operations. These operations needed to have distinct discharges to reasonably sized receiving streams. Identification of such facilities was more difficult than anticipated. Table 3-1 presents a summary of quarries contacted, but not visited, and the reason for their not being selected for field surveys. Figure 3-1 shows the locations of sites selected in this study (one site was visited twice). Figure 3-2 shows the distribution of limestone quarries across the nation. The exact locations and names of the selected quarries are given in Section 5.0.

TABLE 3-1. LIST OF CONTACTED QUARRIES NOT SELECTED FOR FIELD SURVEYS

Quarries/Companies Contacted	Location	Individuals Contacted (Provided information on this number of quarries and their processes)	Comments
Sterling Crushed Stone Co.	Miami, Florida	Arthur Larson (~10)	They had no discharge to a waterway. Mr. Larson indicated that to his knowledge, no one in South Florida discharged to a waterway. This is due to high seepage rates through sedimentation pond bottoms.
Trinity Quarries Co.	Decatur, Alabama	Bobby Lee Waters	They had only a pit discharge after heavy rain.
Bullit Stone Co.	Shepherdsville, Kentucky		Does not discharge.
Kentucky Stone Co.	Louisville, Kentucky	Jay Brown (~15)	We did visit one of their quarries, but they had 14 more that either had 100% recycle or only had intermittent pit discharges.
Hoover, Inc.	Nashville, Tennessee		Recycle with no discharge.
Anchor Stone Co.	Tulsa, Oklahoma	(~5)	No discharge.
Texas Crushed Stone	Austin, Texas		No discharge.
Lonestar Industries	Throughout Texas	(~10)	No discharge.
Parker Brothers	New Braunfels, Texas		No discharge.
Dolese Brothers	Oklahoma City, Oklahoma	Virgil Smith (~10)	Recycle at numerous plants.
Hemphill Bros., Inc.	Seattle, Washington	Wiley Hemphill	Their washing operation discharges to the Pacific Ocean. They have "the lion's share" of washed limestone in the Northwest.
Mulzer Crushed Stone	Tell City, Indiana	Phillip Bakomb (3)	They had no washing operation and discharged to the Ohio River.
Raid Co.	Burlington, Iowa	Ron Garrison (5)	Closed systems

(Continued)

TABLE 3-1. LIST OF CONTACTED QUARRIES NOT SELECTED FOR FIELD SURVEYS (Continued)

Quarries/Companies Contacted	Location	Individuals Contacted (Provided information on this number of quarries and their processes)	Comments
City Quarries	Columbia, Missouri	Ray Bohlken	No discrete discharge, only seepage.
Kaser Co.	Des Moines, Iowa	Jerry Moosebaum	Very small, intermittent washing operation.
General Crushed Stone	Glenn Mills, Pennsylvania	Vern Schneider (~10)	Pit discharge (closed system).
General Crushed Stone	Downingtown	Vern Schneider (~1?)	Pit discharge.
Dolcito Quarry Co.	Birmingham, Alabama		Closed cycle washing operation.
Vulcan Materials	Birmingham, Alabama	Walter Fridley (>10)	There are no plants meeting criteria of a discharge of process water to a small stream.
Martin-Marietta	Raleigh, North Carolina (Eastern Division)	Bill Ross (>10)	There are no plants with washing discharges, only pit dewatering, recycle, or no discharge.
	Iowa (Central Division)	Tom Sellers (>10)	Probably 99% of plants are closed systems. Could not find one which discharged process water.
American Aggregates	Indiana and Ohio	Bill Hole (4)	All but one are pit dewatering only. One is a washing discharge into large lakes and then the Sciota River (too large).
Castle Concrete Co.	Colorado	Charlie Batley (3)	No discharge, water is reused.
General Dynamics	Colorado	Mr. Hartman (3)	No discharge, water shortage
Utah Calcium Co., Inc.	Utah	Unknown	"Mine is in the desert"; no water.

(Continued)

TABLE 3-1. LIST OF CONTACTED QUARRIES NOT SELECTED FOR FIELD SURVEYS (Continued)

Quarries/Companies Contacted	Location	Individuals Contacted (Provided information on this number of quarries and their processes)	Comments
Guernsey Stone Co.	Guernsey, Wyoming	Leonard Wolfe	Water is pumped out of a river, used for dust control. There is no discharge.
Wyoming Construction Co.	Laramie, Wyoming	Unknown, 1 quarry	The operation is a hillside quarry, no crushing, no water. This contact knew of no wet operations in the area. Most limestone in area is in hillside outcrops so there is no ground water encountered.
Kaiser Cement and Gypsum Corp.	Oakland, California	John Winberly	They had no water. There are probably no quarries that discharge.
Austin White Lime	Austin, Texas	Sandra Clare	They had no discharge.
National Lime Association, Texas Division	Waco, Texas	Charlie Baxter	Knew of no quarries or plants discharging, only recycle.
McDonald Brothers	San Antonio, Texas	Larry Irvin	No discharge.
Gifford-Hill	New Braunfels, Texas	Mr. Ivey	No discharge.
H. R. Hemm Quarries	Herrington, Kansas	Clayton Strom	No washing.
Fogle Quarries	Ottowa, Kansas	Unknown	Aggregate, no washing.
Midwest Minerals	Girard, Kansas	Richard Atkinson	No washing.
Reno Construction	Overland Park, Kansas	K. O. Thomas	No discharge, wash water is reused.
Linwood Stone Products	Davenport, Iowa	Gaye Krewer	Discharges to the Mississippi River.
Halquist Stone	Sussex, Wisconsin	Perry Halquist	Declined to participate in study.
Waukesha Lime & Stone	Waukesha, Wisconsin	Mr. Dewey	Declined to participate in study.

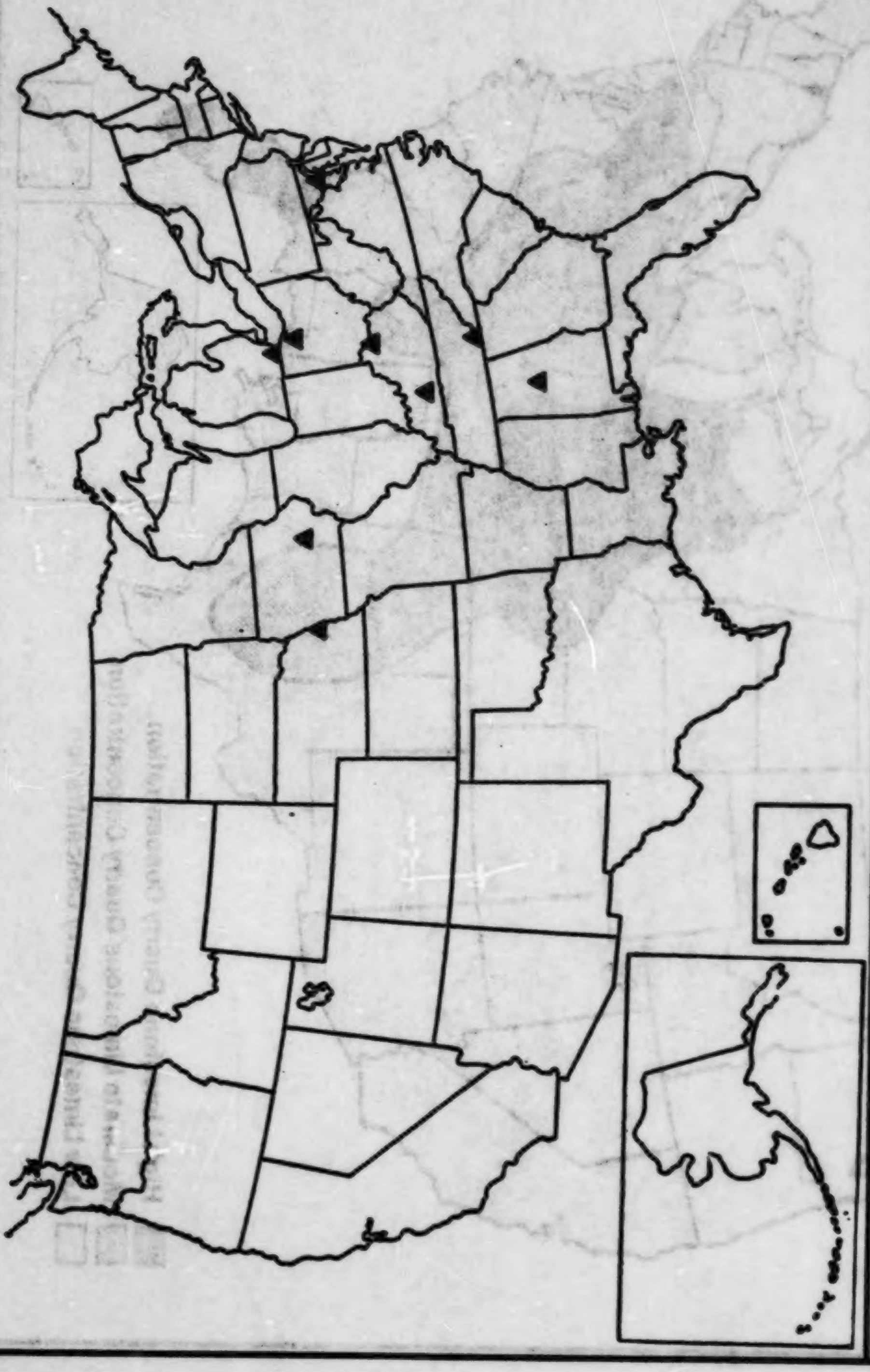

Figure 3-1. Locations of Sites Visited

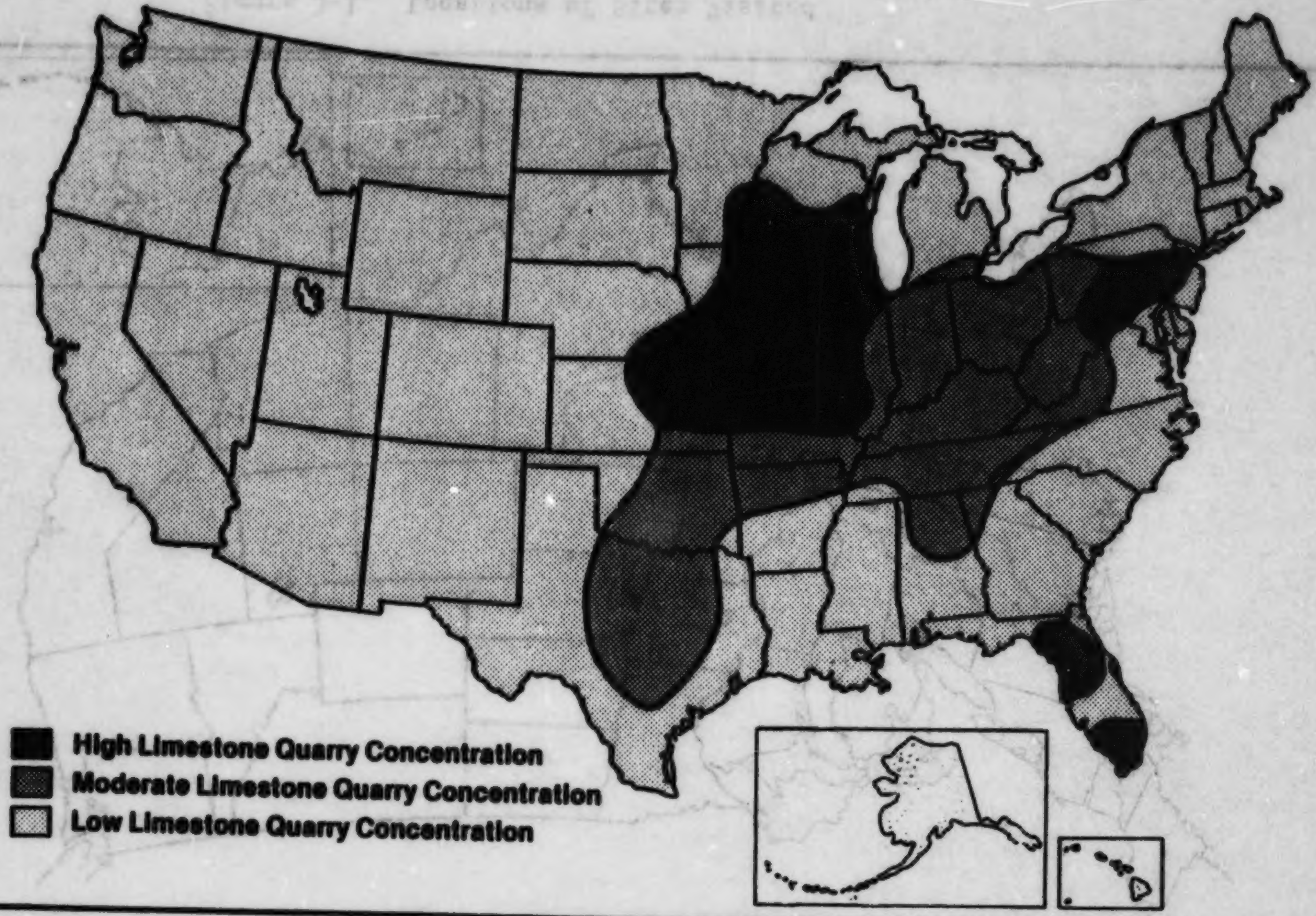
High Limestone Quarry Concentration
Moderate Limestone Quarry Concentration
Low Limestone Quarry Concentration

Figure 3-2. Limestone Quarry Distribution

Surveys were not made to quarries in areas with dry climate, such as the southwest. Quarries in such areas of the country tend to recycle their water, thus having no discharge. Quarries in Florida typically do not discharge because of prohibition by a state law and because the high infiltration rates of most sedimentation pond bottoms leaves no excess water to discharge. The quarries located in the western and mountain states typically do not use a wet process in their process operations. As Figure 3-1 indicates, the sites selected represent a reasonable distribution among the quarries available for sampling.

4.0 DESCRIPTION OF SAMPLING PROCEDURES

Two distinct types of samples were collected at each site: samples related to the quality of untreated and treated waters and samples for the assessment of impact on aquatic biota and water quality of the receiving stream.

4.1 Water Quality

Sample collection points were identified during a tour of each quarry provided by quarry personnel. Sample points generally included: sump discharges, wash water supply, untreated wash wastewater, and treated wash wastewater.

The basic procedure at each station consisted of compositing four samples collected at one hour intervals, and then filling containers with the sample, preserving, and labeling. The procedures are described below in detail.

4.1.1 Sample Collection

At each sample point within a quarry, four water samples were collected at one hour intervals and composited. Hourly samples were 1.5 liters each and were composited in eight (8) liter polyethylene containers. Since the volume of flow upstream of each sample point was controlled by a pump, flows remained relatively constant at each sample point during the sample period. Therefore, flow proportioning of hourly samples was not necessary.

At each station, a grab sample to be analyzed for asbestos was collected in specially cleaned, narrow mouth, one liter polyethylene bottles provided by the Sample Control Center at EPA. The bottle was rinsed three times in the source, filled, and sealed.

4.1.2 Sample Preparation

When four (4) hourly samples were collected and composited, the following procedures were followed for preparing samples to be analyzed for physical parameters (total solids, total dissolved solids, total suspended solids, hardness, silica, turbidity, and pH), total metals, and dissolved metals and asbestos.

Physical Parameters

A 500 ml polyethylene container was filled with the composited sample for the analyses of total solids, total suspended solids, total dissolved solids, hardness, silica, turbidity, and pH. The container was labeled (date, location, station and parameters) and put on ice.

Total Metals

Two one liters polyethylene containers were filled with the composited sample for the analyses of total concentrations of lead, mercury, nickel, chromium, cadmium, selenium, zinc, and acid, labeled, and put on ice. One liter was analyzed using an atomic absorption spectrometer, the other an inductively coupled plasma optical emission spectrometer. (ICP)

Dissolved Metals

Two liters of the composited sample were filtered through an 0.45 micron Milipore filter using a vacuum pump and a Milipore filtering beaker and flask. The filtrate was poured into two one liter polyethylene containers and four milliliters of nitric acid were added for preservation. The containers were labeled and placed on ice. These samples were to be analyzed for the dissolved portion of lead, mercury, nickel, chromium, cadmium, selenium, zinc, and iron. One liter was analyzed using an atomic absorption spectrometer, the other an inductively coupled plasma optical emission spectrometer.

Asbestos

One milliliter of 2.71% mercuric chloride solution was added to the sample and the pH of the sample was measured using hydrion paper. The bottle was then labeled with a Sample Control Center Traffic Report sample number and placed in the shipping container provided.

4.2 Biological Sampling Procedures

The receiving streams into which the limestone quarries discharged effluents were assessed for water quality parameters such as depth, temperature, pH, conductivity, dissolved oxygen, and oxidation-reduction potential. Biotic samples were taken in the receiving stream and analyzed for benthic invertebrates, periphyton, attached algae, plankton, and nekton.

Receiving Stream Water Quality

The water quality of the receiving stream was analyzed with a Hydrolab 8000®. This instrument is capable of analyzing depth, pH, conductivity, temperature, dissolved oxygen, and oxidation-reduction potential. Sites above and below the quarry outfalls were monitored.

4.3 Water Quality Analyses Procedures

The metal parameters for which analyses were performed included total and dissolved lead, mercury, nickel, chromium, cadmium, selenium, zinc, and iron. Analyses for total solids, total dissolved solids, total suspended solids, hardness silica, turbidity, and pH were also performed. Methods of analysis are cited in "Guidelines Establishing Test Procedures for the Analyses of Pollutants", (Federal Register 40 CFR Part 136). All samples were analyzed for the presence of metals by two methods using inductively coupled plasma optical emission spectroscopy (ICP) and atomic adsorption spectroscopy (AA). The analyses for mercury and selenium were by AA only.

Analyses for ICP were performed using methods and techniques described in "Methods for Chemical Analyses of Water and Wastes", published by EPA Environmental Monitoring and Support Laboratory, Cincinnati, Ohio, third edition, March 1979. The method for analyses by ICP is a proposed method cited in the Federal Register, vol. 44, no. 233, December 3, 1979, pp. 69559.

Asbestos analyses were performed using the method outlined in "Preliminary Interim Procedure for Fibrous Asbestos," (published by EPA, Athens, GA). Analyses for total fibers and chrysotile were completed.

Benthic Invertebrates

The benthic invertebrates were sampled with a Modified Ekman dredge. The collected sediments were sieved in the field through a Wildco #119 sieve. All benthic samples were preserved in 5 percent hexamine buffered formalin for transport to the laboratory. In the laboratory the samples were rinsed in ethanol/rose bengal and the invertebrates sorted. Sorted invertebrates were stored in ethanol. Identifications of invertebrates were based on Pennak, 1979; Holsenger, 1972; Burch, 1972; Klemm, 1972, Williams, 1972; Hobbs, 1972, Burch, 1973; Foster, 1972, Ferris, 1972; Kenk, 1972; Brown, 1972; and Needham and Needham, 1962.

Attached Algae and Plankton

Macroscopic attached algae were removed from the substrate by hand and preserved in 2% hexamine buffered. Plankton were collected with a 35 μm mesh phytoplankton net (Biocontrol Corporation, Pt. Sanilac, Michigan). Plankton samples were preserved in 1 percent hexmine buffered formalin and transported to the laboratory for identification. Identifications were based on Bourelly, 1966, 1968, 1970; Chapman, 1962; Patrick and Reimer, 1966; Smith, 1951; Prescott, 1970; and Eyles et al., 1944.

Nekton

Nekton were sampled with minnow seines or throw nets. Samples were preserved in 5 percent formalin for transport to the laboratory. Samples were field identified when appropriate. Identifications were based on Needham and Needham, 1962; Harlan et al., 1951; Eddy et al., 1960; Douglas, 1974; McClane, 1978; and Trautman, 1957.

5.0 DESCRIPTION OF SITES VISITED

5.1 Introduction

In order to assess the ecological impacts of limestone operation effluents upon receiving stream biota, the following criteria were used in site selection:

- quarry operations selected must discharge effluents rather than use closed cycle systems;
- associated receiving waters should be perennial streams or lakes, small enough (physical size and flow quantities) that biological sampling is feasible;
- receiving waters should be relative free from other sources of pollution; and
- selected quarries should be in areas representative of the various ecoregions of the United States.

A total of ten sampling trips were made to nine different facilities. Table 5-1 summarizes the locations, dates, and sample points for this sampling program. Table 5-2 lists the sites by ecoregions, and Figure 5-1 shows that the sites visited provide a good distribution in the ecoregions where quarries meeting the listed criteria exist. The remainder of this section will provide a more detailed description of each site visited. In addition, historical self-monitoring data will be summarized for all facilities.

TABLE 5-1. SUMMARY OF SITES VISITED AND SAMPLE POINTS

Quarry	Location	Date Sampled	Sample Point*	Sample Point Description
Ft. Calhoun Stone Co.	Ft. Calhoun, Nebraska	12/18/79	1	Pit dewatering discharge
			2	Pit dewatering discharge
River Products, Inc.	Iowa City, Iowa	12/19/79	1	Pit dewatering discharge
Stone Man, Inc.	Chattanooga, Tennessee	1/24/80	1	Pit dewatering discharge
			2	Sedimentation pond discharge
Southern Stone Co.	Birmingham, Alabama	1/25/80	1	Pit dewatering discharge
			2	Washing water supply
			3	Untreated washing wastewater
			4	Sedimentation pond effluent
			5	Discharge point of lake
Flintkote Stone Products Co.	Cockeysville, Maryland	2/13-14/80 and 7/24-25/80	1	Untreated washing wastewater
			2	Sedimentation pond effluent

(Continued)

TABLE 5-1. SUMMARY OF SITES VISITED AND SAMPLE POINTS (Continued)

Quarry	Location	Date Sampled	Sample Point*	Sample Point Description
			3	Untreated frother flotation effluent
			4	Frother sedimentation pond effluent
			5	Calcite mine discharge
			6	Pit dewatering discharge
Oldham County Stone Co.	Louisville, Kentucky	2/28/80	1	Pit dewatering discharge
Kentucky Stone Co.	Elkton, Kentucky	2/29/80	1	Pit dewatering discharge
France Stone Co., Monroe Quarry	Monroe, Michigan	5/13/80	1	Pit dewatering and wash water supply
			2	Untreated stone sand washing wastewater
			3	Untreated crushed stone washing wastewater
France Stone Co., Bloomville Quarry	Bloomville, Ohio	7/23/80	1	Pit dewatering discharge

*Sample point numbers correspond to sample location shown on quarry process diagrams in Section 5.2.

TABLE 5-2. QUARRIES LISTED BY ECOREGION

Ecoregion	Quarry
Southeastern Mixed Forest-Outer Coastal Plain Forest	Southern Stone Co. Birmingham, Alabama
	Flintkote Stone Products Co. Cockeysville, Maryland
Eastern Deciduous Forest	The Stone Man, Inc. Chattanooga, Tennessee
	Kentucky Stone Co. Hopkinsville, Kentucky
	Oldham County Stone Louisville, Kentucky
	Monroe Stone Plant Monroe, Michigan
	France Stone Co. Bloomville, Ohio
Tallgrass Prairie	Ft. Calhoun Stone Co. Ft. Calhoun, Nebraska
	River Products, Inc. Iowa City, Iowa

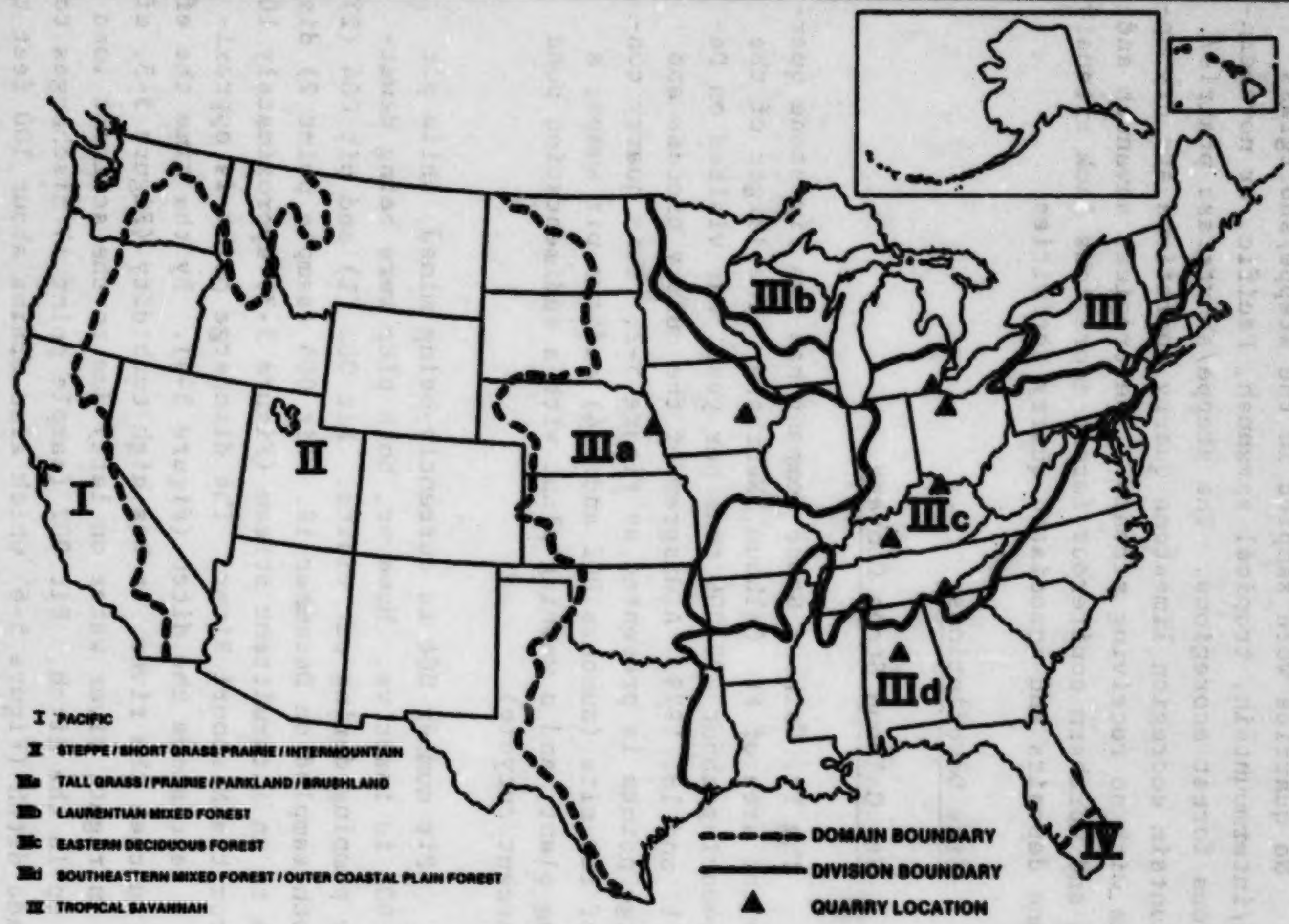
III
IIIb
IIIa
IIIc
IIId
I
II
IV
I PACIFIC
II STEPPE / SHORT GRASS PRAIRIE / INTERMOUNTAIN
IIIa TALL GRASS / PRAIRIE / PARKLAND / BRUSHLAND
IIIb LAURENTIAN MIXED FOREST
IIIc EASTERN DECIDUOUS FOREST
IIId SOUTHEASTERN MIXED FOREST / OUTER COASTAL PLAIN FOREST
IV TROPICAL SAVANNAH
DOMAIN BOUNDARY
DIVISION BOUNDARY
QUARRY LOCATION

Figure 5-1. Limestone Quarries by Ecoregion

No quarries were sampled in the steppe/shortgrass prairie/intermountain, tropical savannah, Pacific, or northern-coniferous forest ecoregions. The steppe/shortgrass prairie/intermountain ecoregion limestone quarry operations are dry operations with no receiving streams. The tropical savannah and Pacific and northern coniferous forest ecoregions lack extensive limestone deposits and associated quarry activities.

5.2 Site Descriptions

Ft. Calhoun Stone Company

The Ft. Calhoun Stone Company has two limestone quarries in the area of Ft. Calhoun, Nebraska. The larger of the two, producing about 400,000 tons per year, was visited on December 17 and 18, 1979. A diagram of the quarry process and discharge points is presented as Figure 5-2. This quarry consists of two pits (numbers 002 and 004) and two pit sumps, a crushing plant, and a washing plant with a sedimentation pond (100 percent recycle).

Pit number 004 is currently being mined, while pit number 002 is inactive. However, both pits were being dewatered by pumping during our visits. Pit 002 (1) and pit 004 (2) were both sampled on December 18. Pit 004 (sample point 2) discharges to an intermittent stream (Figure 5-3) approximately 100 feet from the Missouri River. The discharge point is approximately 6 feet above the ditch (Figure 5-4). By the time the effluent reaches the river, it has high turbidity (Figure 5-5, effluent on right, river water on left) due to the sediment load picked up in the ditch. Pit 002 (sample point 1) discharges to a manmade ditch (Figure 5-6) which also drains about 100 feet to the Missouri River. The discharge is at ground level. The only

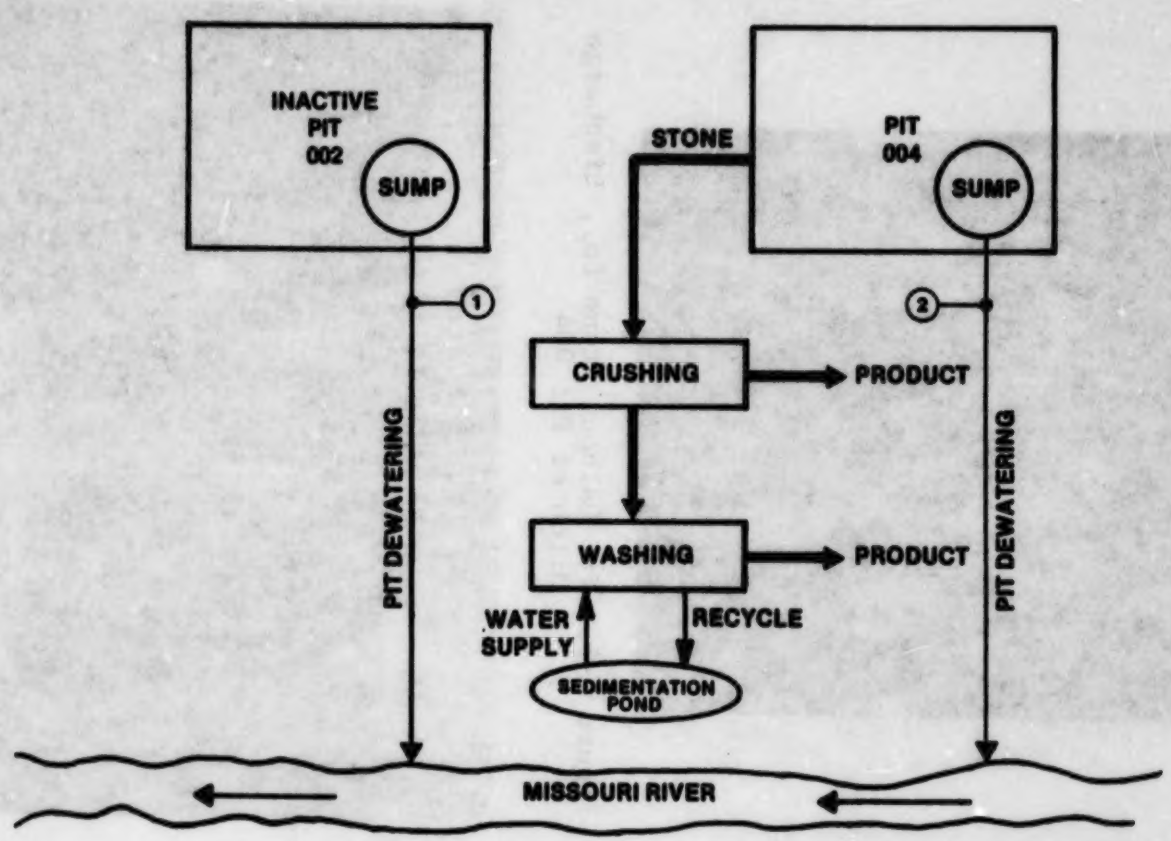
INACTIVE
PIT
002
SUMP
①
PIT DEWATERING
STONE
PIT
004
SUMP
②
CRUSHING
PRODUCT
WASHING
PRODUCT
PIT DEWATERING
WATER SUPPLY
RECYCLE
SEDIMENTATION POND
MISSOURI RIVER

Figure 5-2. Process Diagram, Ft. Calhoun Stone Company, Ft. Calhoun, Nebraska

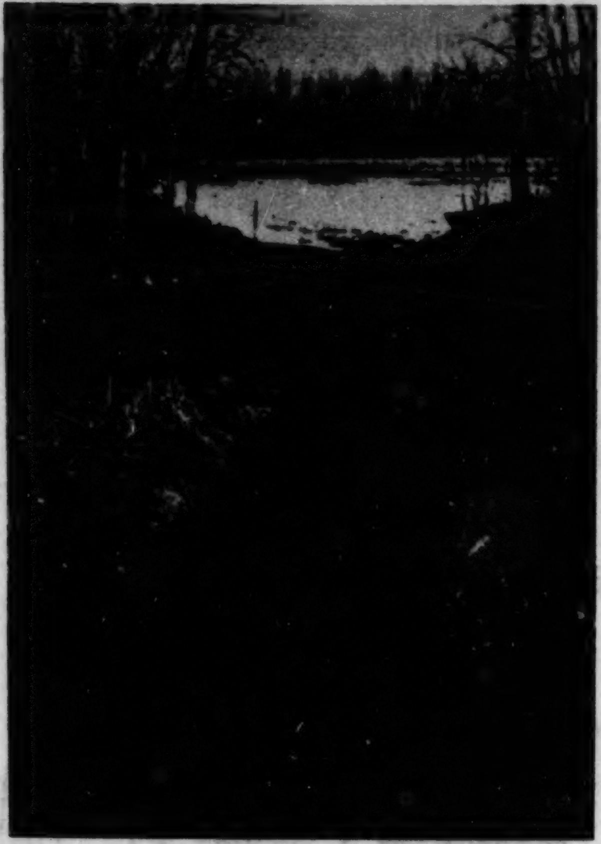

Figure 5-3. Ft. Calhoun Stone Co., Discharge Ditch of Pit 004

Figure 5-4. Ft. Calhoun Stone Co., Pit 004 Discharge

Figure 5-5. Ft. Calhoun Stone Co., Mixing Zone of Pit Discharge 004 Ditch and Missouri River (Effluent on right)

Figure 5-6. Ft. Calhoun Stone Co., Pit Discharge 002

flow in this ditch is the occasional discharge from Pit 002. The effluent is less turbid than the river (Figure 5-7, effluent on right, river water on left).

The washing plant had been shut down for the winter. When in operation, the plant recycles water to and from a sedimentation pond. Due to evaporation and seepage, additional water is occasionally pumped into the pond from the Missouri River, but there is no discharge from the pond.

River Products, Inc.

River Products, Inc. operates the Conklin Quarry located in Iowa City, Iowa. Conklin Quarry has been in operation since 1920, and a new plant was constructed at the quarry in 1970. The crushing plant produces a variety of limestone products including rip-rap, roadstone, asphaltic and concrete aggregate, and agricultural lime. In 1979, this quarry produced 642,000 tons of stone.

A diagram of the quarry operation and discharges is presented as Figure 5-8. The only discharge from Conklin Quarry at the time of sampling was a discharge from the pit sump to the Iowa River. The pit sump discharge was sampled at sample point (1) on December 19, 1979. The pit water is made-up of groundwater seepage, storm runoff, and percolation from the wastewater sedimentation pond which is separated from the pit sump by a gravel dam. The water supply for the stone washing plant is from the Iowa River and discharge is directly to the river (Figure 5-9).

The Stone Man, Inc.

The Rossville Quarry of the Stone Man, Inc. is located in Chattanooga, Tennessee. This quarry, which produces about 500,000 tons per year of crushed stone, was visited on January 24, 1980.

Figure 5-7. Ft. Calhoun Stone Co., Mixing Zone of Pit Discharge 002 Ditch and Missouri River (Effluent on right)

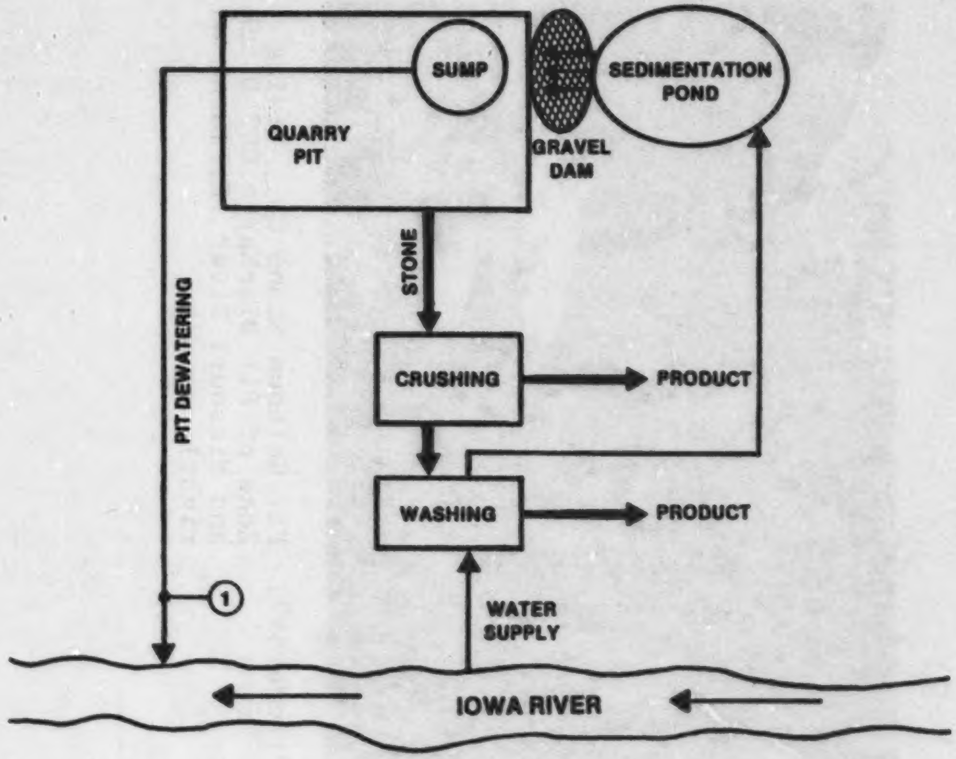
SUMP
SEDIMENTATION POND
QUARRY PIT
GRAVEL DAM
STONE
PIT DEWATERING
CRUSHING
PRODUCT
WASHING
PRODUCT
①
WATER SUPPLY
IOWA RIVER

Figure 5-8. Process Diagram, River Products, Inc., Iowa City, Iowa

Figure 5-9. River City Products. Discharge into Iowa River

As illustrated in Figure 5-10, the Rossville plant consists of a ten acre pit, a pit sump, and one crushing plant with a washing operation available when needed. A settling pond on the site (created from an inactive pit) receives the pit dewatering discharge from the active pit as well as storm runoff. The washing wastewater is not routed to the settling pond but is discharged onto the ground around the washing plant. A small portion may drain into the settling pond. The settling pond is the water supply for the washing operation.

The water quality samples were collected at two points within the Rossville Quarry: the pit discharge to the settling pond (1) and the settling pond effluent (2). The settling pond effluent flows into a drainage ditch which flows into Dry Creek. The Creek drains a rural, primarily agricultural watershed. Above the quarry outfall the creek was clear (Figure 5-11), but below the outfall (Figures 5-12 and 5-13), the creek was turbid. This turbidity was not entirely a result of limestone quarry operations, but rather to sediments picked up by the effluent stream prior to the effluent stream reaching the creek. After discharge from the final settling pond (Figure 5-14, lower right) the effluent crosses a quarry roadbed which is traveled by large trucks. In the process, the stream acquires a large sediment load. The effluent is then ditched past a diesel oil storage tank (Figure 5-15), under a road, and eventually into the creek (Figure 5-16), creating a large mixing plume of sediment laden water (Figure 5-17).

Southern Stone Company

The Maylene Quarry of Southern Stone Company is located south of Birmingham, Alabama. This quarry consists of a 40 acre pit and a wet crushing plant which produces about 800,000 tons per year of dolomitic limestone products.

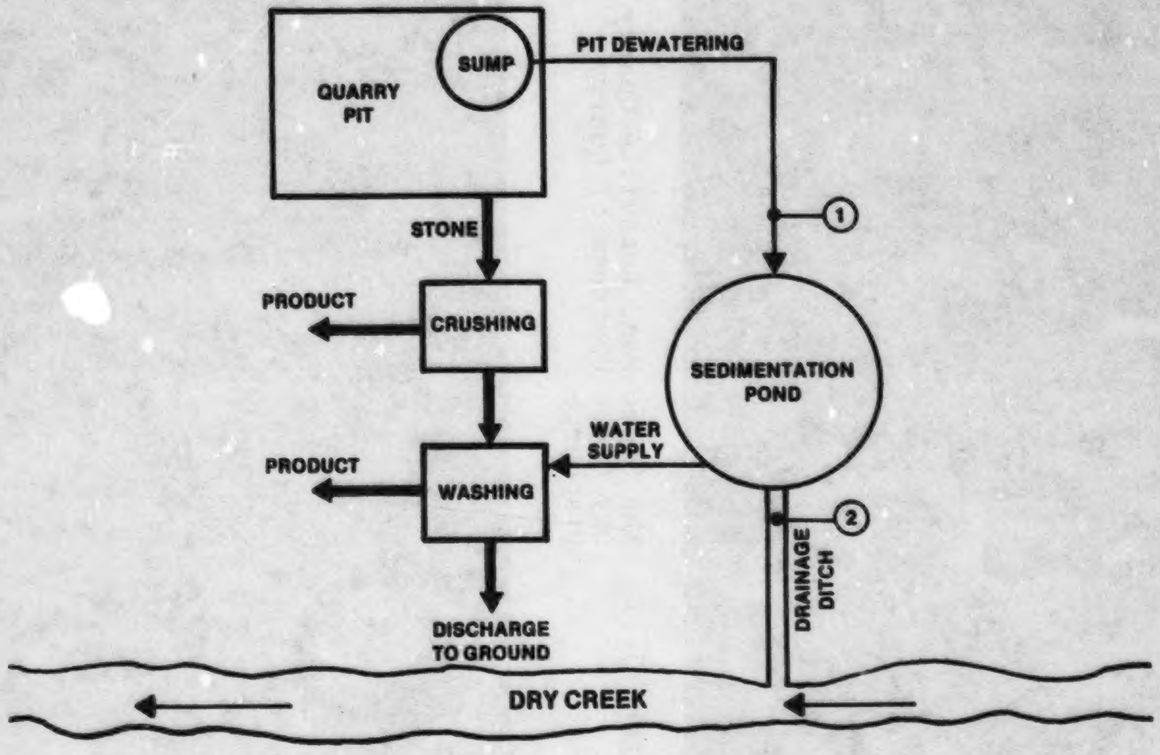
QUARRY PIT
SUMP
PIT DEWATERING
STONE
①
PRODUCT
CRUSHING
SEDIMENTATION POND
WATER SUPPLY
PRODUCT
WASHING
②
DRAINAGE DITCH
DISCHARGE TO GROUND
DRY CREEK

Figure 5-10. Process Diagram, The Stone Man, Inc., Chattanooga, Tennessee

Figure 5-11. The Stone Man, Rossville Quarry Dry Creek Upstream of Quarry Discharge

Figure 5-12. The Stone Man, Rossville Quarry. Dry Creek Downstream of Quarry Discharge

Figure 5-13. The Stone Man, Rossville Quarry. Dry Creek Downstream of Quarry Discharge

Figure 5-14. The Stone Man, Rossville Quarry. Discharge from Final Settling Pond (Lower right) as it crosses road bed (Center of figure)

Figure 5-15. The Stone Man, Rossville Quarry. Drainage Ditch (Upper left) Flowing Near Oil Storage Tanks

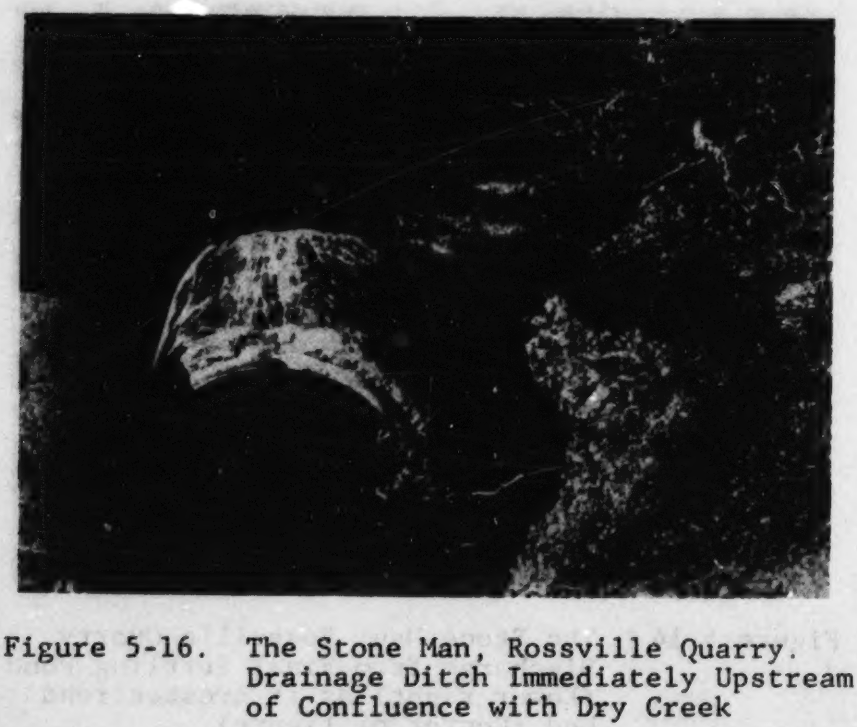

Figure 5-16. The Stone Man, Rossville Quarry. Drainage Ditch Immediately Upstream of Confluence with Dry Creek

Figure 5-17. The Stone Man, Rossville Quarry. Mixing Zone of Sediment Laden Quarry Discharge with Clear Dry Creek Water

Figure 5-18 is a diagram of the quarry elements and discharge. The central element of this quarry's treatment system is a small lake. This lake receives the pit dewatering discharge from the pit sump. Water from the lake is used for washing and the wash wastewater is discharged to a sedimentation pond which discharges back into the lake. During wet weather the lake discharges to an intermittent creek; otherwise the quarry has a closed cycle treatment system.

At the time that this quarry was sampled, the sedimentation pond receiving wastewater from the washing plant was completely filled with sediment because the dredging equipment was inoperative and under repair. The wash wastewater flowed over the surface of the sediment and discharged from the pond within a few minutes of entering. The results of the suspended solids analyses in Section 6.1 indicate that the pond was providing virtually no treatment to the wastewater under such operating conditions.

The effluent from the sedimentation pond flowed into the small lake, which was shallow near the sedimentation pond outfall because of sediment deposition. The dam at the outfall from the lake was enlarged with a load of fill in an attempt to raise the water level in the lake, and there was no discharge from the lake.

Water quality samples were collected on January 25, 1980 from the pit dewatering discharge to the lake (1), the washing supply water from the lake (2), the washing wastewater (3), the sedimentation pond discharge (4) and from the lake near the normal discharge point (5) (although it was not discharging at the time).

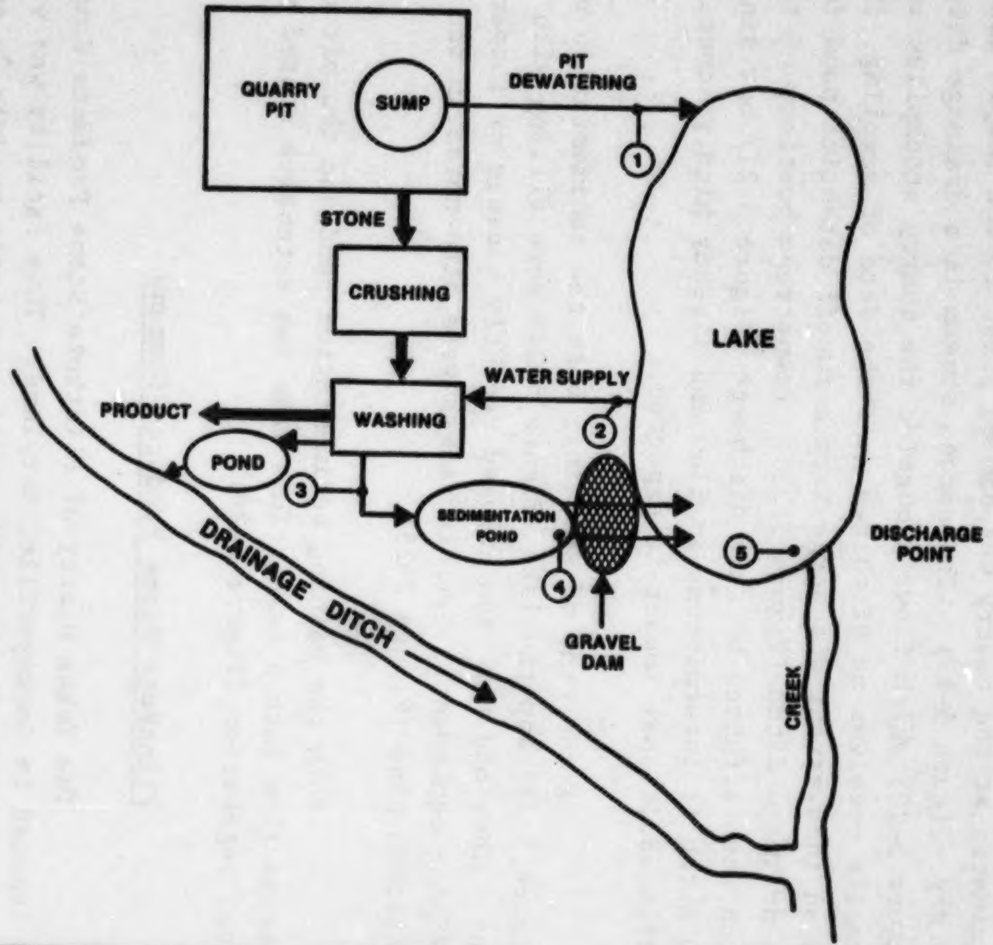
QUARRY PIT
SUMP
PIT DEWATERING
1
STONE
CRUSHING
LAKE
WATER SUPPLY
2
PRODUCT
WASHING
POND
3
SEDIMENTATION POND
4
5
DISCHARGE POINT
GRAVEL DAM
DRAINAGE DITCH
CREEK

Figure 5-18. Process Diagram, Southern Stone Company, Birmingham, Alabama

There are two small streams draining the quarry site. One originates at the lake outfall of the quarry, and the other is a small ditch that originates near the railroad embankment which borders the end of the quarry property. The stream which originates at the quarry was dammed prior to the sample date and was dry (Figure 5-19). The second stream is a drainage ditch (Figure 5-20) which flows alongside the quarry stockpiles and normally receives no discharge. At the date of sampling, there was an inadvertent discharge from a runoff detention pond into the drainage ditch (Figure 5-21). Downstream portions of the ditch were affected by this discharge (Figure 5-22) but since the ditch is intermittent in flow and already highly impacted, little additional impact is expected.

At the time of sampling, both the sedimentation pond (Figure 5-23) and the lake (Figure 5-24) were filling with sediment. They had not been dredged recently because of inoperative dredging equipment. Oil discharges were also noted in the sedimentation pond (Figure 5-25).

Both the washing sedimentation pond and the pit discharges flow into a lake. This lake has extensive rooted marginal vegetation (Figure 5-26).

Flintkote Stone Products Company

The Texas Quarry of Flintkote Stone Products Company is located in Cockeysville, Maryland. This facility was visited twice, first on February 13 and 14, and again on July 24 and 25, 1980. This quarry has been in operation since 1927 and is one of the largest quarries in the United States, producing approximately 3 million tons per year of limestone products. A diagram of this operation is included as Figure 5-27. The Texas Quarry

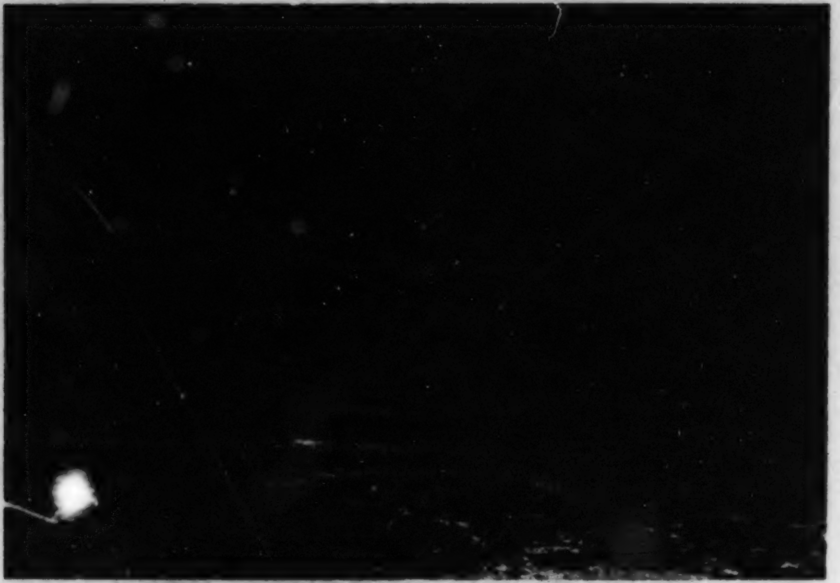

Figure 5-19. Southern Stone Co., Maylene Quarry. Dry Bed of Dammed Drainage Creek

Figure 5-20. Southern Stone Co., Maylene Quarry. Drainage Ditch at Perimeter of Quarry Property

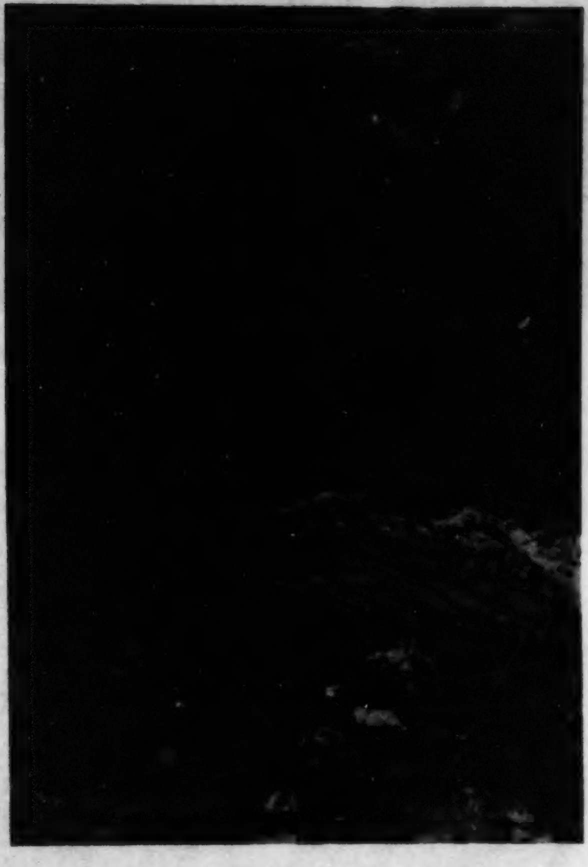

Figure 5-21. Southern Stone Co., Maylene Quarry. Runoff Detention Pond Discharge Into Drainage Ditch

Figure 5-22. Southern Stone Co., Maylene Quarry. Drainage Ditch Downstream of Runoff Detention Pond Discharge

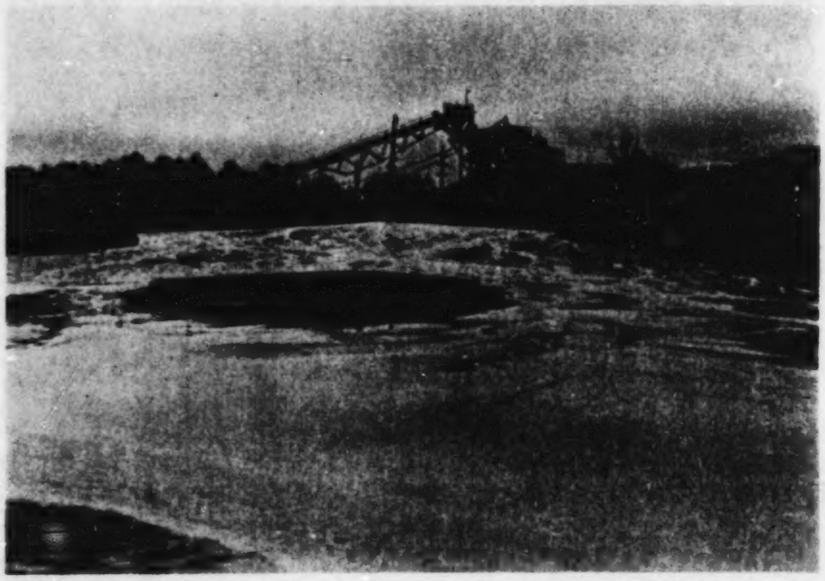

Figure 5-23. Southern Stone Co., Maylene Quarry. Filled-in Sedimentation Pond

Figure 5-24. Southern Stone Co., Maylene Quarry. Lake Filling in with Overflow From Sedimentation Pond

Figure 5-25. Southern Stone Co., Maylene Quarry. Oil on Surface of Water in Sedimentation Pond

Figure 5-26. Southern Stone Co., Maylene Quarry. Emergent Macrophytes Near Pit Dewatering Discharge

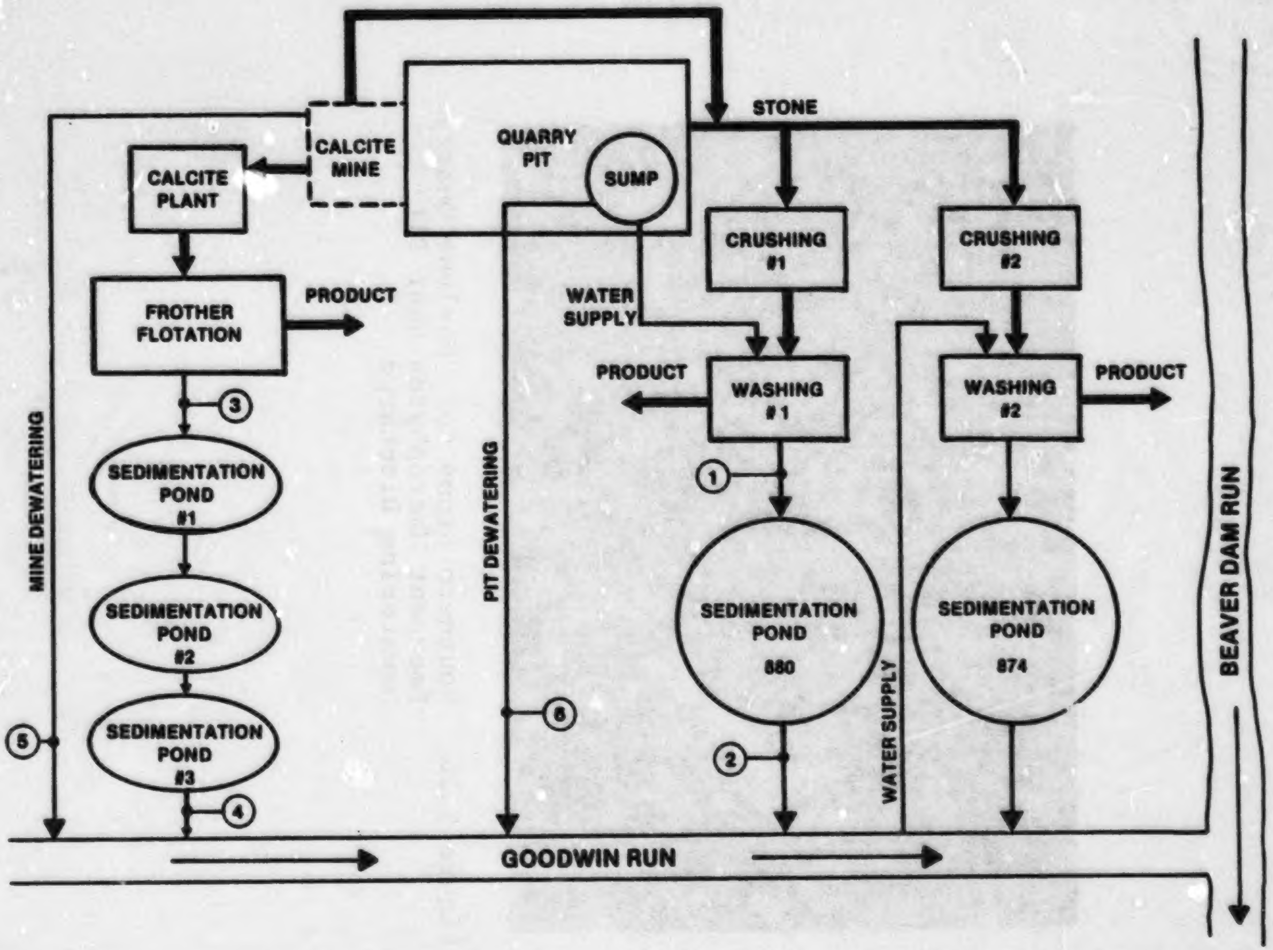
STONE
CALCITE MINE
QUARRY PIT
SUMP
CALCITE PLANT
FROTHER FLOTATION
PRODUCT
CRUSHING #1
CRUSHING #2
WATER SUPPLY
PRODUCT
WASHING #1
WASHING #2
PRODUCT
MINE DEWATERING
PIT DEWATERING
SEDIMENTATION POND #1
SEDIMENTATION POND #2
SEDIMENTATION POND #3
SEDIMENTATION POND 880
SEDIMENTATION POND 874
WATER SUPPLY
BEAVER DAM RUN
GOODWIN RUN
1
2
3
4
5
6

Figure 5-27. Process Diagram, Flintkote Stone Products Company, Cockeysville, Maryland

consists of an 80 acre open pit quarry and an underground calcite mine. Plants and treatment systems include two wet crushing operations, two sedimentation ponds for washwater treatment, a calcite plant (Atlantic Carbonate) with a flotation frother treatment discharge to a series of three sedimentation ponds, a calcite mine water discharge and a quarry pit water discharge. All discharges are to Goodwin Run, a tributary of Beaver Dam Run.

Samples were taken on February 13 at the following points:

1. raw washing wastewater influent to sedimentation pond number 880 (1);
2. treated effluent from sedimentation pond number 880 (2);
3. flotation frother effluent (3) (influent to sedimentation pond series);
4. effluent from sedimentation pond series (4); and
5. underground mine water discharge (5).

The pit water was not being discharged during the sampling period. The second sedimentation pond (number 874) was not sampled because it was only receiving runoff from a watering truck filling line which discharged onto the ground most of the time.

Goodwin Run is a small perennial urban-suburban stream in the Loch Raven Reservoir watershed. Loch Raven Reservoir is the primary source of drinking water for the city of Baltimore. Goodwin Run flows through an industrial area before reaching the quarry site (Figure 5-28) and is subjected to runoff and discharge from industry and from areas of impermeable cover. Construction is proceeding on a 3200 unit subdivision immediately upstream from the quarry.

The bed of Goodwin Run upstream from the quarry site was littered with household trash (Figure 5-29). On the plant site, Goodwin Run is cobble bottomed upstream from the quarry discharges (Figure 5-30) but as sediment is added (Figure 5-31), the bottom of the creek becomes covered with a fine sediment (Figure 5-32).

Beaver Dam Run showed no pronounced sediment accumulation immediately downstream (approximately one-half mile) from the confluence with Goodwin Run (Figure 5-33).

Oldham County Stone Company

The Oldham County Stone/Brownsboro Quarry is located in Crestwood, Kentucky, near Louisville. This quarry, which was sampled on February 28, 1980, produced 238,000 tons of crushed limestone products per year in 1978 and 431,000 tons per year in 1979.

This quarry, as diagrammed in Figure 5-34, consists of one pit with a sump discharge and a crushing plant. The crushing plant, which is a dry crushing operation, was shut down for winter maintenance. The only water discharge is pit dewatering from the pit sump, and this discharge was sampled (1). The receiving stream is a small tributary to Harrod's Creek.

Figure 5-28. Flintkote Stone Products Co., Texas Quarry. Goodwin Run Upstream of Quarry Looking Downstream

Figure 5-29. Flintkote Stone Products Co., Texas Quarry. Goodwin Run Upstream of Quarry Looking Downstream

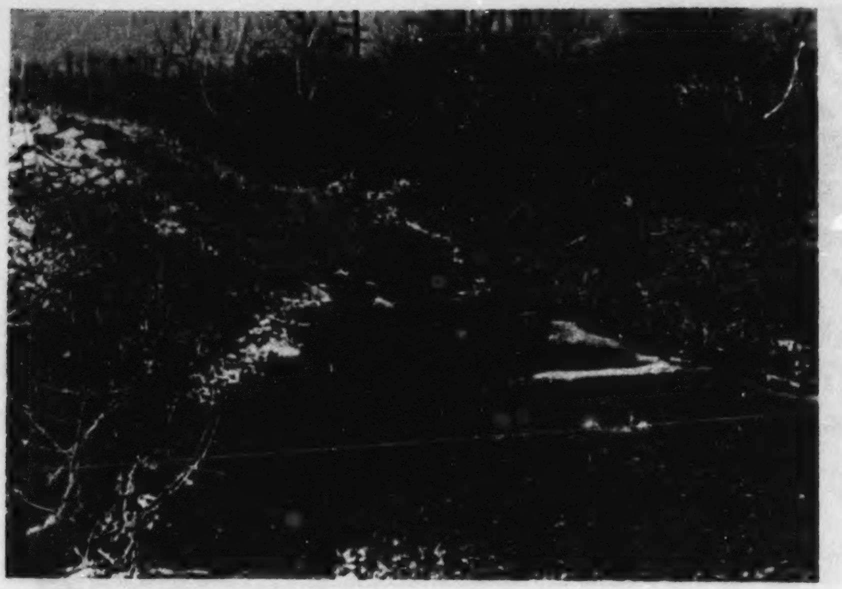

Figure 5-30. Flintkote Stone Products Co., Texas Quarry. Goodwin Run on Quarry Site Upstream of First Discharge

Figure 5-31. Flintkote Stone Products Co., Texas Quarry. Goodwin Run at Calcite Mine Discharge

Figure 5-32. Flintkote Stone Products Co., Texas Quarry. Goodwin Run Upstream of Discharge from Sedimentation Pond 880

Figure 5-33. Flintkote Stone Products Co., Texas Quarry. Beaver Dam Run Downstream of Confluence with Goodwin Run

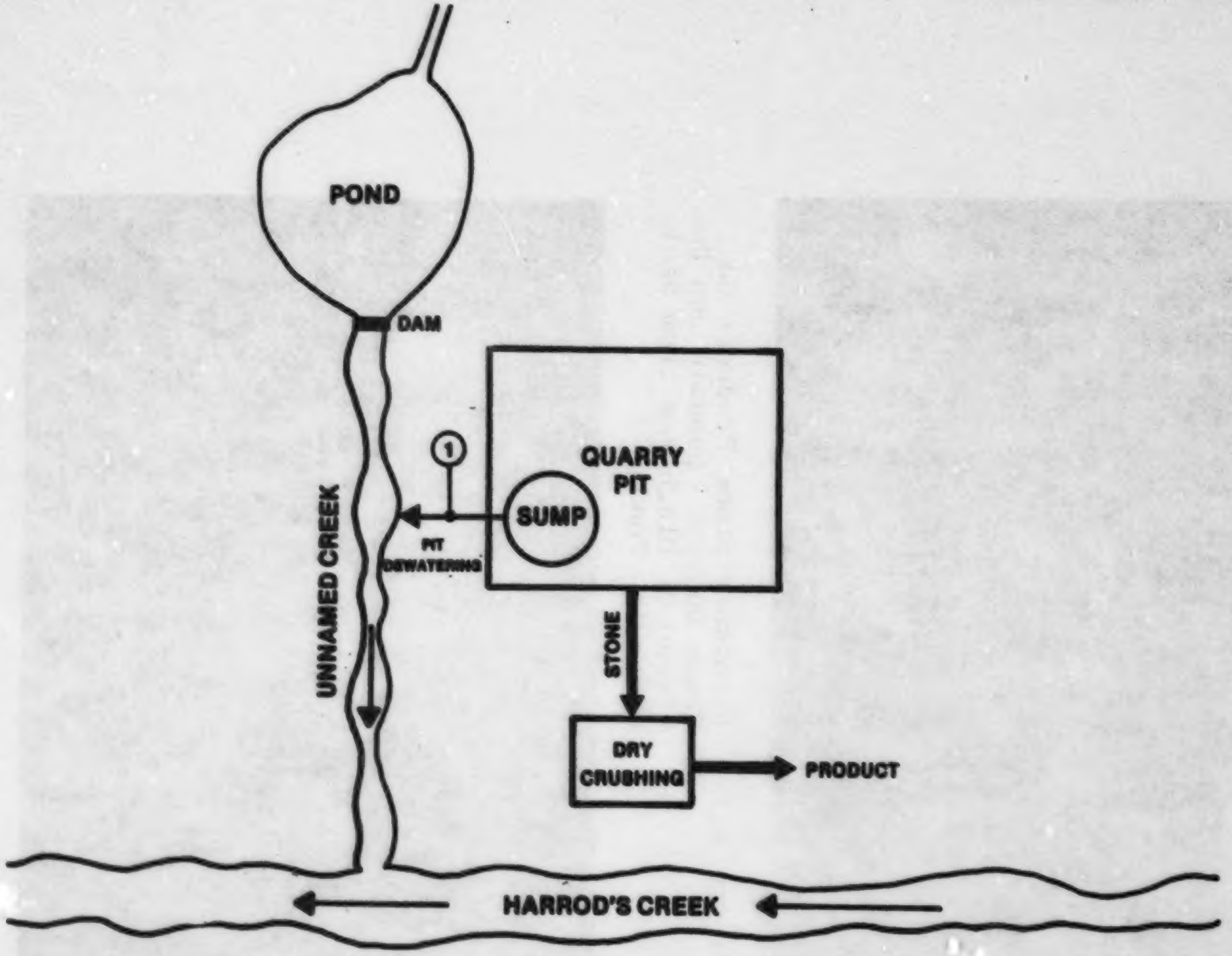
POND
DAM
UNNAMED CREEK
1
PIT DEWATERING
SUMP
QUARRY PIT
STONE
DRY CRUSHING
PRODUCT
HARROD'S CREEK

Figure 5-34. Process Diagram, Oldham County Stone Company, Louisville, Kentucky

The tributary is very small, arising from a pond on the plant property and flowing one-half mile to the confluence with Harrod's Creek. The receiving creek has a high gradient with two small waterfalls above the junction with Harrod's Creek.

The pond which serves as the source of the creek is formed as an impoundment on a drainage ditch and apparently the ditch has a loading of organic wastes as the bottom was coated with a dense stand of blue-green and green algae.

Kentucky Stone Company

The Todd County Quarry of Kentucky Stone Company was visited on February 29, 1980. This quarry, located near Elkton in southwest Kentucky, produces approximately 200,000 tons per year of crushed limestone. Product sizes range from rip-rap to agricultural lime.

Figure 5-35 is a diagram of the quarry and discharge. There is no washing of products, and the only discharge is from the quarry pit sump which receives runoff during storm events. The discharge is to a drainage ditch, and samples of this discharge were collected (1).

France Stone Company, Monroe Quarry

The France Stone Company Monroe Quarry, located in Monroe, Michigan, was sampled on May 13, 1980. This quarry produces about 1,500,000 tons per year of crushed limestone and stone sand.

Figure 5-36 is a diagram of the quarry and discharges. The quarry consists of a pit and pit sump, a primary crusher, a

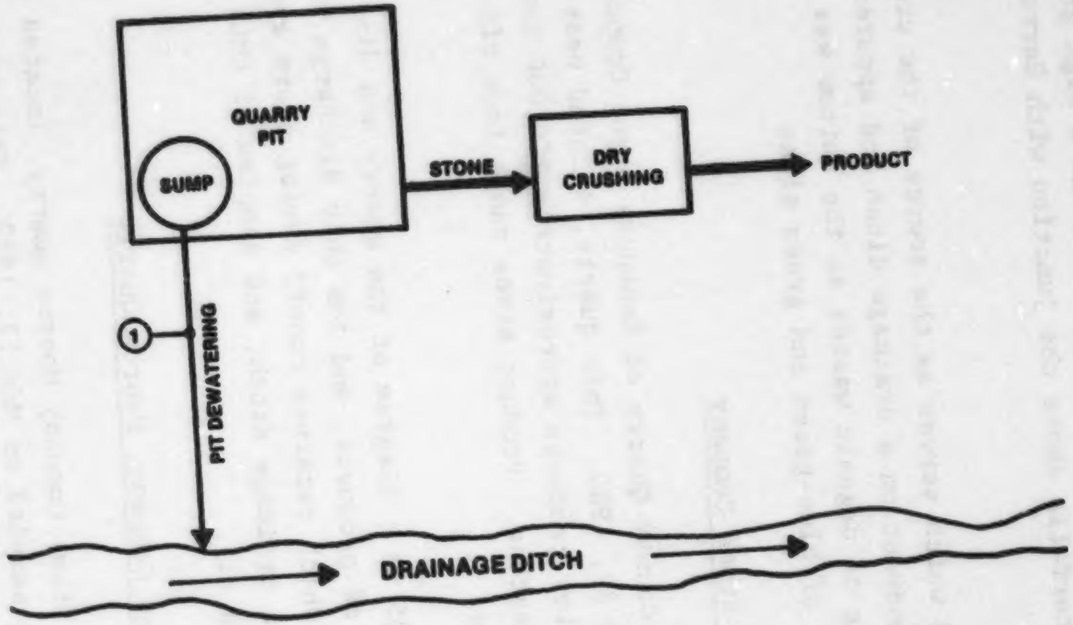
QUARRY PIT
SUMP
STONE
DRY CRUSHING
PRODUCT
PIT DEWATERING
1
DRAINAGE DITCH

Figure 5-35. Process Diagram, Kentucky Stone Company, Elkton, Kentucky

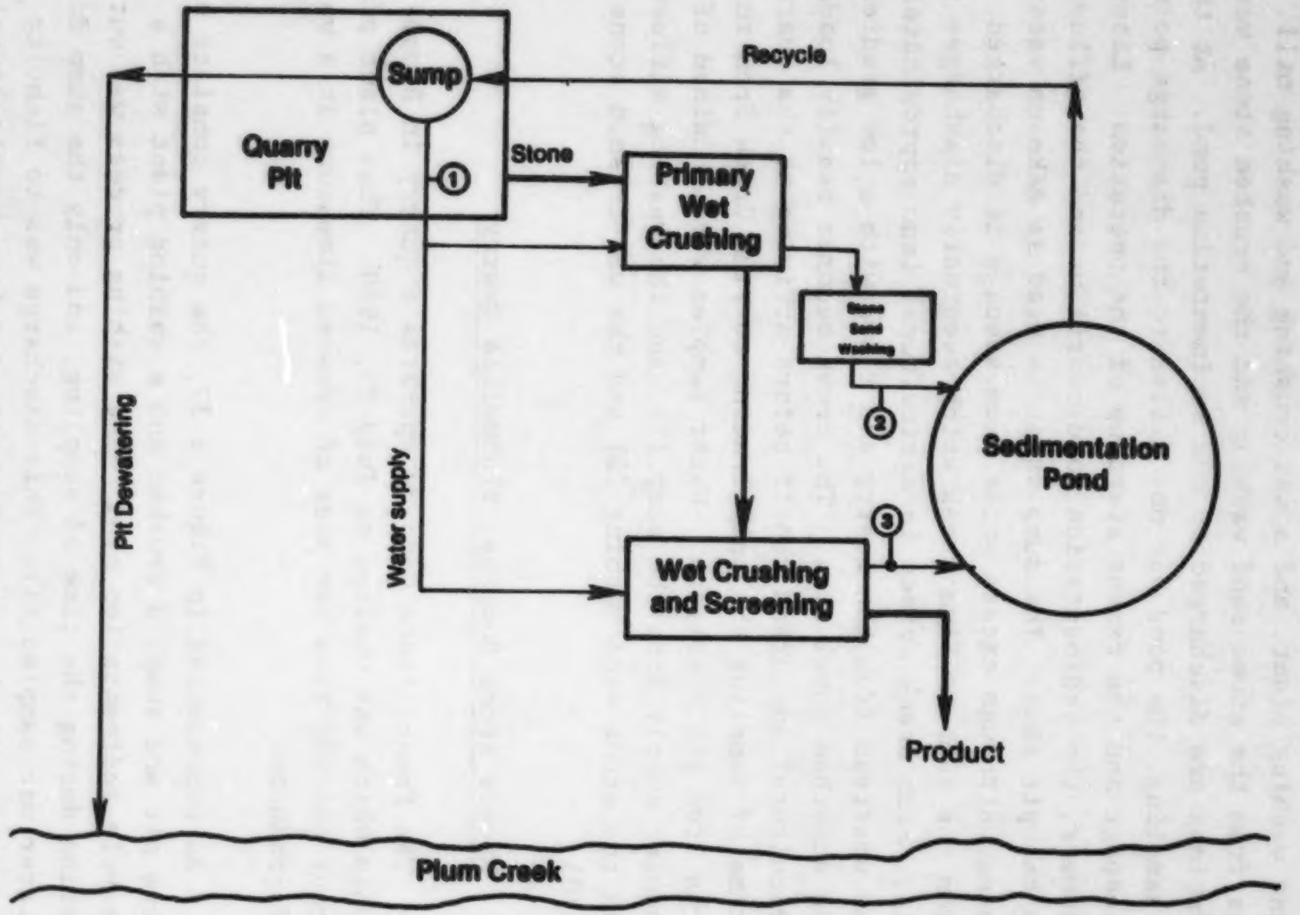
Quarry Pit
Sump
①
Stone
Recycle
Water supply
Pit Dewatering
Primary Wet Crushing
Stone Sand Washing
②
Sedimentation Pond
③
Wet Crushing and Screening
Product
Plum Creek

Figure 5-36. Process Diagram, France Stone Company, Monroe Quarry, Monroe, Michigan

stone sand washing plant, and a wet crushing and washing mill. Effluents from the stone sand washing and the crushed stone washing operations are discharged to one sedimentation pond. At the time of sampling, the pond has not filled to the discharge point due to seepage and the recent start-up of the operation. Later in the summer, the sedimentation pond overflows and the effluent flows to the pit sump. The sump water is used as make-up water for washing, although excess water from seepage is discharged daily from the sump to Plum Creek which eventually discharges into Lake Erie. Plum Creek arises in agricultural land approximately ten miles upstream from the quarry and flows with a low gradient through a suburban-rural area. The creek becomes heavily loaded with agricultural and urban runoff before arriving at the quarry. At the time of sampling the only loading to Plum Creek from the quarry was from pit discharge. Water samples were obtained of the washwater supply from the sump (1), and the washing effluent from both the stone sand washing (2) and the wet crushed stone washing (3).

France Stone Company, Bloomville Quarry

The France Stone Company operates a quarry in Bloomville, Ohio which was visited on July 23, 1980. This plant produces about 600,000 tons per year of crushed limestone in a variety of products.

As represented in Figure 5-37, the quarry consists of a 110-acre pit and sump, a crusher and a washing plant with a total recycle sedimentation pond. The washing process was out of operation during the time of sampling, and only the sump discharge water was sampled (1). This discharge was to Eicholtz Ditch. Existing discharges to Eicholtz Ditch are agricultural and rural. The ditch has a small drainage area and has been dammed downstream of the plant site to form a small lake.

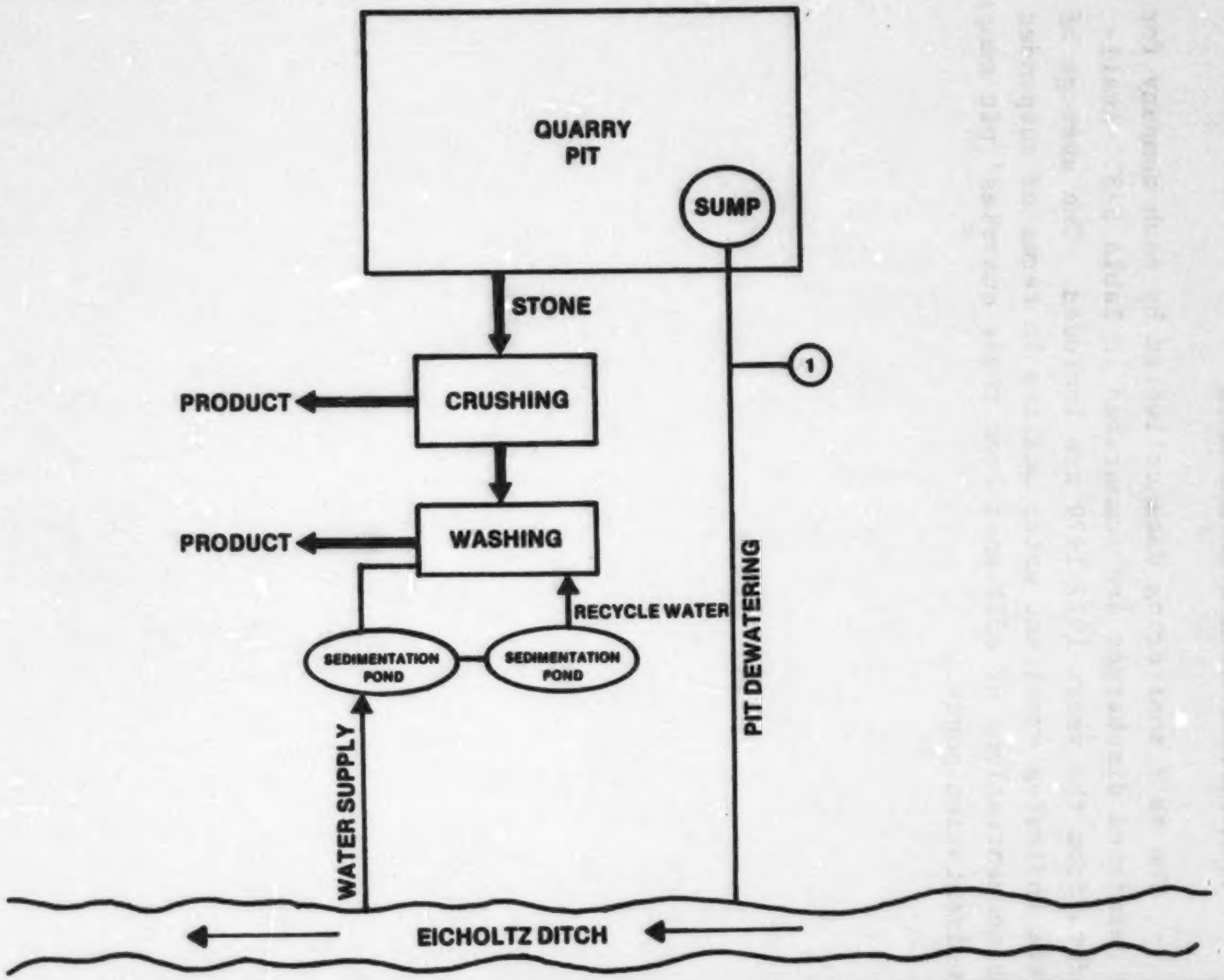
QUARRY PIT
SUMP
STONE
1
CRUSHING
PRODUCT
WASHING
PRODUCT
RECYCLE WATER
SEDIMENTATION POND
SEDIMENTATION POND
WATER SUPPLY
PIT DEWATERING
EICHOLTZ DITCH

Figure 5-37. Process Diagram, France Stone Company, Bloomville Quarry, Bloomville, Ohio

5.3 Self-Monitoring Historical Data

The self monitoring data collected by each company for their permitted discharges are summarized in Table 5-3. Available data from the years 1977-1979 are included. The average of all data indicates excellent water quality in terms of suspended solids concentrations of effluents from these quarries' pit sumps and sedimentation ponds.

TABLE 5-3. SUMMARY OF HISTORICAL PERFORMANCE OF LIMESTONE QUARRY DISCHARGES (for 1977-1979)

Facility Discharge (and corresponding sample point number from Table 5-1)	Historical Performance			
	Total Suspended Solids (mg/1)		pH (SU)[1] Range	Discharge (MGD)[2]
	Average	Maximum		
Ft. Calhoun Stone Co.				
Pit Discharge (Inactive Pit) (1)	7.1	13.0	7.6-7.9	0.4
Pit Discharge (Active Pit) (2)	13.8	20.3	7.4-8.3	0.6
River Products, Inc.				
Pit Discharge (1)	29.0	100.0	6.2-8.0	0.2
The Stone Man, Inc.				
Pond Effluent (2)	10.4	28.0	6.7-8.0	0.8
Southern Stone Company				
Pit Discharge (1)	2.3	14.5	7.3-8.2	0.3
Settling Pond (5)	2.5	6.0	7.3-8.3	-
Flintkote Stone Products Company				
Sedimentation Pond (2)	4.5	11.0	7.0-8.0	0.5
Pit Discharge (6)	4.2	11.0	6.8-8.1	1.3
Mine (5)	29.8	134.0	7.0-8.5	1.0
Calcite Sedimentation (4)	15.7	68.0	6.7-8.0	0.3
Oldham County Stone Company				
Pit Discharge (1)	5.7	25.0	6.9-8.1	0.1
Kentucky Stone Company				
Pit Discharge (1)	6.6	36.4	7.2-7.8	0.2
France Stone Company, Monroe Quarry				
Pit Discharge (1)	6.0	25.8	6.6-8.0	1.0
France Stone Company, Bloomville Quarry				
Pit Discharge (1)	1.8	7.0	7.1-8.1	0.4

[1] Standard Units

[2] Million Gallons per Day

6.0 RESULTS OF SAMPLE ANALYSES

6.1 Water Quality Analyses

The water quality characteristics of the various discharges and flow streams sampled are characterized in this section. Refer to Table 5-1 for descriptions of the sampling locations to which these results correspond. The parameters analyzed are divided into three categories:

Physical Parameters

Total solids, total dissolved solids, total suspended solids, silica, hardness, turbidity, and pH.

Heavy Metals

Lead, mercury, nickel, chromium, cadmium, selenium, zinc, and iron.

Asbestos

Total fibers, chrysotile fibers.

Table 6-1 presents the results of the physical parameter analyses. Although there is considerable variation of results among all samples, a correlation can be seen between type of discharge and range of concentration. Table 6-2 presents the data divided into categories of treated effluent, untreated wastewater, and pit discharge. Untreated washing wastewaters have significantly higher ranges (and median values) for total solids, TSS, turbidity, and hardness, than do either treated effluents (sedimentation pond effluents) or pit dewatering discharges.

TABLE 6-1. PHYSICAL PARAMETERS ANALYSES RESULTS FOR LIMESTONE QUARRY DISCHARGES

Site and Sample Point	Total Solids (mg/1)	TDS (mg/1)	TSS (mg/1)	Silica SiO_2 (mg/1)	Hardness as $CaCO_3$ (mg/1)	Turbidity FTU	pH
Ft. Calhoun Stone Co.							
1. Pit Discharge 002 (Inactive Pit)	951	947	3.9	8.7	550	1.5	7.66
2. Pit Discharge 004 (Active Pit)	673	669	4.2	11.0	440	16.0	7.63
River Products, Inc.							
1. Pit Discharge	728	693	3.5	5.3	480	<1.0	7.54
Stone Man, Inc.							
1. Pit Discharge	277	231	17.0	5.0	163	16.0	8.10
2. Pond Effluent	267	223	1.2	3.4	158	12.0	8.27
Southern Stone Co.							
1. Pit Discharge	317	265	4.0	4.6	232	8.0	8.30
2. Washwater Supply (From Lake)	1,110	312	716.0	4.4	271	>250.0	8.21
3. Washing Wastewater (Before Settling)	19,700	490	15,800.0	4.5	950	>250.0	8.05
4. Settling Pond Effluent (To Lake)	20,800	431	18,900.0*	4.5	1,010	>250.0	7.90

*This value is from a failed settling pond (completely filled with sediment) and is not used in comparative analyses which follow.

(Continued)

TABLE 6-1. PHYSICAL PARAMETERS ANALYSES RESULTS FOR LIMESTONE QUARRY DISCHARGES (Continued)

Site and Sample Point	Total Solids (mg/l)	TDS (mg/l)	TSS (mg/l)	Silica SiO_2 (mg/l)	Hardness as $CaCO_3$ (mg/l)	Turbidity FTU	pH
5. Lake at Discharge Point	319	259	8.8	3.2	223	9.0	7.76
Flintkote Stone Products Co.							
(February 13)							
1. Washing Wastewater (Before Settling)	937	450	355.0	9.0	287	62.0	7.89
2. Settling Pond Effluent	497	467	<1.0	8.5	264	10.0	7.93
3. Frother Effluent[1] (Before Detention Ponds)	44,100	177	39,600.0	5.5	9,900	>250.0	8.04
4. Frother Detention Pond[1] Discharge	245	230	3.1	2.7	170	11.0	8.07
5. Underground Mine Dewatering Discharge	339	269	52.0	11.0	212	30.0	8.13
Oldham County Stone							
1. Pit Discharge	606	595	<1.0	2.0	430	<1.0	8.13

(Continued)

TABLE 6-1. PHYSICAL PARAMETERS ANALYSES RESULTS FOR LIMESTONE QUARRY DISCHARGES (Continued)

Site and Sample Point	Total Solids (mg/1)	TDS (mg/1)	TSS (mg/1)	Silica SiO_2 (mg/1)	Hardness as $CaCO_3$ (mg/1)	Turbidity FTU	pH
Kentucky Stone Co.							
1. Pit Discharge	319	313	<1.0	2.7	150	1.5	8.28
France Stone Co., Monroe Quarry							
1. Pit Discharge	1,900	1,800	3.1	6.04	1,272	1.0	7.49
2. Mill Washing Wastewater	27,000	9,600	16,000.0	6.92	1,500	>250.0	7.34
3. Stone Washing Wastewater	7,000	1,900	4,100.0	6.64	1,350	>250.0	7.53
France Stone Co., Bloomville Quarry							
1. Pit Discharge	802	630	2.0	0.58	453	1.0	8.15
Flintkote Stone Products Co. (July 24)							
1. Washing Wastewater (Before Settling)	680	392	168.0	0.88	220	32.0	7.98
2. Settling Pond Effluent	424	338	13.0	0.77	207	1.0	8.15
3. Frother Effluent[1] (Before Detention Ponds)	37,631	132	11,198.0	0.62	3,500	13,400.0	8.19

(Continued)

TABLE 6-1. PHYSICAL PARAMETERS ANALYSES RESULTS FOR LIMESTONE QUARRY DISCHARGES (Continued)

Site and Sample Point	Total Solids (mg/1)	TDS (mg/1)	TSS (mg/1)	Silica SiO_2 (mg/1)	Hardness as $CaCO_3$ (mg/1)	Turbidity FTU	pH
4. Frother Detention Pond[1] Discharge	268	218	19.0	0.47	133	1.0	7.86
6. Pit Discharge	532	436	62.0	0.94	253	13.0	7.89

[1] Calcite frother operations are not typically present at limestone crushing and washing facilities.

TABLE 6-2. PHYSICAL PARAMETERS ANALYSES FOR VARIOUS TYPES OF PROCESSES

Type of Sample	Total Solids (mg/l)	Total Suspended Solids (mg/l)	Total Dissolved Solids (mg/l)	Turbidity (FTU)	Hardness as $CaCO_3$ (mg/l)	Silica (mg/l)	pH (SU)
Sedimentation Pond Effluent (4 samples)							
Range	267-497	<1-13.0	223-467	1-12	158-264	0.8-8.5	7.76-8.15
Median	372	5	299	9	219	3.3	
Untreated Washing Wastewater (5 samples)							
Range	680-27,000	168-16,000	392-9,600	32->250	220-1,500	0.9-9.0	7.34-8.05
Median	7,000	4,100	490	>250	950	6.6	
Pit Dewatering Discharge (10 samples)							
Range	277-1,900	<1-62	231-1,800	<1-16	150-1,272	0.6-11.0	7.49-8.30
Median	640	3.7	613	1.5	435	4.8	

The results of the heavy metals analyses are presented in Tables 6-3 through 6-10. Metal concentrations were analyzed by atomic absorption (AA) and inductively coupled plasma optical spectrometer (ICP). In some cases the results for the same sample differed by more than an order of magnitude between the two methods of analysis. Possible explanations for such variations include the inaccuracies which occur at such low concentration levels as are found in these samples, inter-elemental interference which can occur in the ICP method, and possible ICP inaccuracies.

Due to the general high integrity of the AA method of metals analysis, only AA results are summarized in Table 6-11. The results of analyses by AA are presented in Table 6-11 and have again been divided into various categories of discharge types. The laboratory results from the last two quarries sampled (Flintkote Stone Products Co. and France Stone Co., Bloomville Quarry) are not included in this summary table because the detection limits for these samples were higher than the water quality criteria to which the results are being compared. As a result, these high detection limits interfere with the comparative analysis. Another note concerning Table 6-11 is that a number of different laboratories performed the analyses of samples collected at the quarries. The detection limits used in the analyses varied among the labs such that the reported results for some metals may simply range from one detection limit to another.

Iron appears to be the only element where significant concentrations have occurred in all three processes. Especially high concentrations appear in the untreated wastewater (before sedimentation) as total iron. By comparing the high total iron with the low dissolved iron in the untreated wastewater category, it can be seen that almost all of the iron is in the particulate form.

TABLE 6-3. ANALYSES RESULTS - LEAD

		Concentrations of Lead (mg/l)			
		Total		Dissolved	
Quarry	Sample Point*	PES	AAS	PES	AAS
Ft. Calhoun Stone Company	1	.059	<.050	.091	<.050
	2	.042	<.050	.070	<.050
River Products, Inc.	1	.035	<.030	.042	<.030
Stone Man, Inc.	1	.033	<.025	.198	.035
	2	.049	<.025	.062	<.025
Southern Stone Co.	1	.094	<.025	.110	<.025
	2	.057	<.025	<.040	<.025
	3	1.550	.110	.144	<.025
	4	1.040	.184	<.040	<.025
	5	.121	<.025	.116	<.025
Flintkote Stone Products Co. (February 13)	1	.120	<.050	<.040	<.050
	2	<.040	<.050	.048	.250
	3	5.170	.130	<.040	<.050
	4	<.040	<.050	<.040	<.050
	5	<.040	<.050	<.040	<.050
Oldham County Stone Company	1	.040	<.030	.028	<.030
Kentucky Stone Co.	1	.028	<.030	.032	<.030
France Stone Co. Monroe Quarry	1	.042	<.030	.058	<.030
	2	.252	<.030	.069	<.030
	3	.828	.060	.080	<.030
France Stone Co. Bloomville Quarry	1	<.050	.110	<.050	.110
Flintkote Stone (July 24)	1	<.050	.130	<.050	<.100
	2	<.050	<.100	<.050	<.100
	3	<.050	<.100	<.050	<.100
	4	<.050	<.100	<.050	<.100
	6	<.050	<.100	<.050	<.100

*Refer to Table 5-1.

TABLE 6-4. METALS ANALYSES RESULTS - MERCURY

Quarry	Sample Point*	Concentrations of Mercury** (mg/1) Total AAS	Dissolved AAS
Ft. Calhoun Stone Co.	1	.001	.001
	2	<.001	<.001
River Products, Inc.	1	<.001	<.001
Stone Man, Inc.	1	<.001	<.001
	2	<.001	<.001
Southern Stone Co.	1	<.001	<.001
	2	<.001	<.001
	3	.001	<.001
	4	.001	<.001
	5	<.001	<.001
Flintkote Stone Products Co. (February 13)	1	<.001	<.001
	2	<.001	<.001
	3	<.001	<.001
	4	<.001	<.001
	5	<.001	<.001
Oldham County Stone Co.	1	<.002	<.002
Kentucky Stone Co.	1	<.002	<.002
France Stone Co. Monroe Quarry	1	<.001	<.001
	2	<.001	<.001
	3	<.001	<.001
France Stone Co. Bloomville Quarry	1	<.0006	<.0006
Flintkote Stone Products Co. (July 24)	1	<.0006	<.0006
	2	<.0006	<.0006
	3	<.0006	<.0006
	4	<.0006	<.0006
	6	<.0006	<.0006

*Refer to Table 5-1.
**Analyzed by AAS only.

TABLE 6-5. ANALYSES RESULTS - NICKEL

		Concentrations of Nickel (mg/l)			
		Total		Dissolved	
Quarry	Sample Point*	PES	AAS	PES	AAS
Ft. Calhoun Stone Co.	1	.052	<.040	.058	<.040
	2	.039	<.040	.055	.051
River Products, Inc.	1	.284	.040	.280	.040
Stone Man, Inc.	1	.127	<.030	.145	<.030
	2	.135	<.030	.147	<.030
Southern Stone Co.	1	<.005	<.013	<.005	<.013
	2	.053	.017	.020	<.013
	3	.332	.177	<.005	<.013
	4	.246	.215	.031	.014
	5	<.005	<.013	<.005	<.036
Flintkote Stone Products Co. (February 13)	1	.021	<.013	.010	<.013
	2	.007	<.013	.020	<.013
	3	.436	.108	<.005	<.013
	4	.018	<.013	<.005	.014
	5	.018	<.013	.012	<.013
Oldham County Stone Co.	1	.165	<.004	.155	<.004
Kentucky Stone Co.	1	.085	<.004	.082	<.004
France Stone Co. Monroe Quarry	1	.492	.050	.539	<.030
	2	.879	.030	.540	<.030
	3	1.463	.115	.574	.035
France Stone Co. Bloomville Quarry	1	<.050	<.100	<.050	<.100
Flintkote Stone Products Co. (July 24)	1	<.050	<.100	<.050	<.100
	2	.050	<.100	<.050	<.100
	3	.080	.180	<.050	<.100
	4	.050	<.100	<.050	<.100
	6	.050	<.100	<.050	<.100

*Refer to Table 5-1.

TABLE 6-6. METALS ANALYSES RESULTS - CHROMIUM

Quarry	Sample Point*	Concentrations of Chromium (mg/l)			
		Total		Dissolved	
		PES	AAS	PES	AAS
Ft. Calhoun Stone Co.	1	.016	<.030	.019	<.030
	2	.007	<.030	.017	<.030
River Products, Inc.	1	.035	<.004	.035	<.004
Stone Man, Inc.	1	.012	<.020	.013	<.020
	2	.013	<.020	.013	<.020
Southern Stone Co.	1	<.001	<.015	<.001	<.015
	2	.047	.058	.008	<.015
	3	.545	.168	<.001	.016
	4	.387	.202	.009	<.015
	5	<.001	<.015	<.001	<.015
Flintkote Stone Products Co. (February 13)	1	.023	<.004	.007	<.004
	2	.012	<.004	.014	.015
	3	.316	.124	<.001	<.004
	4	.009	<.004	<.001	<.004
	5	.010	<.004	.005	<.004
Oldham County Stone Co.	1	.037	<.020	.037	<.020
Kentucky Stone Co.	1	.015	<.020	.014	<.020
France Stone Co. Monroe Quarry	1	.052	<.050	.055	<.050
	2	.201	<.050	.062	<.050
	3	.414	<.050	.061	<.050
France Stone Co. Bloomville Quarry	1	<.010	<.100	<.010	<.100
Flintkote Stone Products Co. (July 24)	1	<.010	<.100	<.010	<.100
	2	<.010	<.100	<.010	<.100
	3	.074	.180	<.010	<.100
	4	<.010	<.100	<.010	<.100
	6	<.010	<.100	<.010	<.100

*Refer to Table 5-1.

TABLE 6-7. METALS ANALYSES RESULTS - CADMIUM

Quarry	Sample Point*	Concentrations of Cadmium (mg/l)			
		Total		Dissolved	
		PES	AAS	PES	AAS
Ft. Calhoun Stone Co.	1	<.002	<.005	.003	<.005
	2	<.002	<.005	<.002	<.005
River Products, Inc.	1	.002	<.003	.003	<.003
Stone Man, Inc.	1	.002	.004	.007	<.004
	2	.004	<.004	.005	.004
Southern Stone Co.	1	<.002	<.005	<.002	<.005
	2	<.002	<.005	<.002	<.005
	3	.054	<.005	<.002	<.005
	4	.036	<.005	<.002	<.005
	5	<.002	<.005	<.002	<.005
Flintkote Stone Products Co. (February 13)	1	.012	<.005	.008	<.005
	2	.007	<.005	.010	<.005
	3	.388	<.005	.007	<.005
	4	.006	<.005	.005	<.005
	5	.006	<.005	.007	<.005
Oldham County Stone Co.	1	<.001	<.004	<.001	<.004
Kentucky Stone Co.	1	.001	<.004	.001	<.004
France Stone Co. Monroe Quarry	1	<.001	<.003	.001	.006
	2	.010	.003	.002	<.003
	3	.044	<.003	.005	<.003
France Stone Co. Bloomville Quarry	1	<.005	<.020	<.005	<.020
Flintkote Stone Products Co. (July 24)	1	<.005	<.020	<.005	<.020
	2	<.005	<.020	<.005	<.020
	3	<.005	<.020	<.005	<.020
	4	<.005	<.020	<.005	<.020
	6	<.005	<.020	<.005	<.020

*Refer to Table 5-1.

TABLE 6-8. METALS ANALYSES RESULTS - SELENIUM

		Concentrations of Selenium** (mg/l)	
Quarry	Sample Point*	Total AAS	Dissolved AAS
Ft. Calhoun Stone Co.	1	.010	.010
	2	.006	.004
River Products, Inc.	1	<.005	<.005
Stone Man, Inc.	1	<.005	<.005
	2	<.005	<.005
Southern Stone Co.	1	<.001	<.001
	2	.001	<.001
	3	<.001	<.001
	4	.002	<.001
	5	<.001	<.001
Flintkote Stone Products Co. (February 13)	1	<.001	<.001
	2	<.001	<.001
	3	.006	.002
	4	<.001	<.001
	5	.002	<.001
Oldham County Stone Co.	1	<.003	<.003
Kentucky Stone Co.	1	<.003	<.003
France Stone Co. Monroe Quarry	1	<.005	<.005
	2	<.005	<.005
	3	<.005	<.005
France Stone Co. Bloomville Quarry	1	<.010	<.010
Flintkote Stone Products Co. (July 24)	1	<.010	<.010
	2	<.010	<.010
	3	<.010	<.010
	4	<.010	<.010
	6	<.010	<.010

*Refer to Table 5-1.

**Analyzed by AAS only.

TABLE 6-9. METALS ANALYSES RESULTS - ZINC

Quarry	Sample Point*	Concentrations of Zinc (mg/l)			
		Total		Dissolved	
		PES	AAS	PES	AAS
Ft. Calhoun Stone Co.	1	.024	.016	.035	.019
	2	.013	<.013	.020	.080
River Products, Inc.	1	.034	<.004	.025	<.004
Stone Man, Inc.	1	.025	<.005	.043	<.005
	2	.036	.015	.072	.005
Southern Stone Co.	1	.001	.025	<.001	<.013
	2	.112	.103	.008	<.013
	3	.395	.141	.005	.029
	4	.282	.164	.009	.026
	5	.001	<.013	<.001	.026
Flintkote Stone Products Co. (February 13)	1	.040	<.010	.018	<.010
	2	.015	<.010	.028	<.010
	3	.528	.286	.007	<.010
	4	.015	<.010	.010	<.010
	5	.014	<.010	.021	.015
Oldham County Stone Co.	1	.047	.012	<.001	<.007
Kentucky Stone Co.	1	.013	.017	.032	.022
France Stone Co. Monroe Quarry	1	.041	.013	.040	.023
	2	.183	.126	.116	.014
	3	.203	.078	.051	.010
France Stone Co. Bloomville Quarry	1	<.010	<.020	<.010	<.020
Flintkote Stone Products Co. (July 24)	1	<.010	<.020	<.010	<.020
	2	.039	.044	<.010	<.020
	3	.180	.240	<.010	<.020
	4	.040	.038	<.010	<.020
	6	.010	<.020	<.010	<.020

*Refer to Table 5-1.

TABLE 6-10. METALS ANALYSES RESULTS - IRON

Quarry	Sample Point*	Concentrations of Iron (mg/l)			
		Total		Dissolved	
		PES	AAS	PES	AAS
Ft. Calhoun Stone Co.	1	.117	.214	<.001	<.100
	2	.539	.272	<.001	.137
River Products, Inc.	1	.094	.168	.027	.107
Stone Man, Inc.	1	.207	.190	.028	.050
	2	.108	.120	.024	.035
Southern Stone Co.	1	<.001	.052	<.001	<.100
	2	5.230	88.800	.072	<.100
	3	89.900	81.000	<.001	<.100
	4	68.800	258.000	.008	<.100
	5	<.001	.083	<.001	<.100
Flintkote Stone Products Co. (February 13)	1	1.800	1.470	.056	<.100
	2	.035	<.100	.031	<.100
	3	68.700	70.000	.006	<.100
	4	.146	.164	.001	<.100
	5	.023	<.100	.001	<.100
Oldham County Stone Co.	1	.135	.130	.089	.030
Kentucky Stone Co.	1	.113	.110	.032	.050
France Stone Co. Monroe Quarry	1	.123	.110	.063	.060
	2	6.570	8.670	.136	<.025
	3	40.500	37.000	.055	.030
France Stone Co. Bloomville Quarry	1	.090	.110	.042	<.100
Flintkote Stone Products Co. (July 24)	1	1.390	1.480	<.030	<.100
	2	.090	.110	<.030	<.100
	3	82.200	79.200	.030	<.100
	4	.450	.480	<.030	<.100
	6	.140	.170	<.030	<.100

*Refer to Table 5-1.

TABLE 6-11. RANGE OF HEAVY METAL CONCENTRATIONS ANALYSES FOR VARIOUS TYPES OF PROCESSES* (Concentrations in mg/l, Atomic Absorption Spectrometer Method)

Heavy Metal	Pit Dewatering Discharge		Sedimentation Pond Effluent		Untreated Washing Wastewater	
	Min	Max	Min	Max	Min	Max
Lead						
Total	<.025 -	<.050	<.025 -	<.050	<.030 -	.110
Dissolved	<.025 -	<.050	<.025 -	.250	<.025 -	<.050
Mercury						
Total	<.001 -	<.002	<.001**		<.001 -	.001
Dissolved	<.001 -	<.002	<.001**		<.001**	
Nickel						
Total	<.004 -	.050	<.013 -	<.030	<.013 -	.177
Dissolved	<.004 -	.051	<.013 -	.036	<.013 -	.035
Chromium						
Total	<.004 -	<.050	<.004 -	<.020	<.004 -	.168
Dissolved	<.004 -	<.050	<.015 -	<.020	<.004 -	<.050
Cadmium						
Total	<.003 -	<.005	<.004 -	<.005	<.003 -	<.005
Dissolved	<.003 -	.006	.004 -	<.005	<.003 -	<.005
Selenium						
Total	<.001 -	.010	<.001 -	<.005	<.001 -	<.005
Dissolved	<.001 -	.010	<.001 -	<.005	<.001 -	<.005
Zinc						
Total	<.004 -	.025	<.010 -	.015	<.010 -	.141
Dissolved	<.004 -	.080	.005 -	.026	<.010 -	.029
Iron						
Total	.052 -	.272	.083 -	.120	1.470 -	81.00
Dissolved	.030 -	.137	.035 -	<.100	<.025 -	<.100

*Samples from the quarries were analyzed by a number of different laboratories. Detection limits varied from lab to lab for the same parameter.

**All values were reported as <.001.

form. By comparing total iron in the untreated wastewater with total iron in the treated wastewater (sedimentation pond effluent), it is also evident that a very high percentage of the iron is removed by sedimentation ponds. Other than iron, the heavy metals are primarily in the dissolved form.

Table 6-12 presents the asbestos analyses results. From this table it can be seen that half of the quarries sampled contained detectable concentrations of chrysotile asbestos fiber. It can also be seen that sedimentation ponds remove a very high percentage of these fibers. For the February 13 visit, comparison of Flintkote sample point 1 with sample point 2 shows a 97% removal and point 3 to point 4 also shows a 97% removal for total chrysotile fibers.

6.2 Ecological Analyses

6.2.1 Ft. Calhoun Stone Company

Both quarry pits were being pumped during the time of sampling. No plankton was present in either of the discharge channels. Drainage channel 002 had extensive stands of dry cattails (Typha) and knotweed (Polygonum) from the previous growing season.

The total suspended solids of the 002 channel, <10 mg/l, was lower than the TSS of the Missouri River (Table 6-13). The TSS of channel 004, 28 mg/l (Table 6-13), was higher than the river water because of sediments scoured from the bottom of the drainage channel.

No biological samples were taken of the Missouri River because of adverse ice conditions. It is expected that the impacts to the Missouri River from Calhoun Stone Company are minimal because of the large volume and turbid nature of the river.

TABLE 6-12. CONCENTRATIONS OF ASBESTOS FIBERS OCCURRING IN WATER AT LIMESTONE MINES (All concentrations are expressed in units of million fibers per liter)

Site and Sampling Point	Total Fibers (all sizes)	Chrysotile Fibers (all sizes)	Total Fibers (restricted sizes)*	Chrysotile Fibers (restricted sizes)*	Detection Limit
Ft. Calhoun Stone Co.					
1. Pit Discharge (Inactive Pit)	2.3	ND	ND	ND	0.5
2. Pit Discharge (Active Pit)	10.1	ND	ND	ND	0.7
River Products, Inc.					
1. Pit Discharge	ND	ND	ND	ND	0.7
Stone Man, Inc.					
1. Pit Dewatering	2.6	ND	ND	ND	0.4
2. Pond Effluent	7.2	1.1	0.4	0.4	0.4
Flintkote Stone Products Co. (February 13)					
1. Washing Wastewater	430.0	330.0	54.4	46.0	4.2
2. Settling Pond Effluent	23.3	9.7	1.8	1.2	0.2

(Continued)

TABLE 6-12. CONCENTRATIONS OF ASBESTOS FIBERS OCCURRING IN WATER AT LIMESTONE MINES (All concentrations are expressed in units of million fibers per liter) (Continued)

Site and Sampling Point	Total Fibers (all sizes)	Chrysotile Fibers (all sizes)	Total Fibers (restricted sizes)*	Chrysotile Fibers (restricted sizes)*	Detection Limit
3. Frother Effluent[1]	76.8	18.8	2.3	0.8	0.8
4. Frother Detention Pond[1]	8.7	0.5	ND	ND	0.2
5. Underground Mine Dewatering Discharge	120.0	77.9	11.3	11.3	1.1
Oldham County Stone					
1. Pit Discharge	2.5	ND	ND	ND	0.1
Kentucky Stone Co.					
1. Pit Discharge	16.0	0.3	ND	ND	0.3
France Stone Co. Monroe Quarry					
1. Pit Discharge	1.13	ND	ND	ND	0.09
2. Mill Washing Wastewater	835.0	390.0	ND	ND	56.0
3. Stone Washing Wastewater	1.6	0.5	ND	ND	0.5

(Continued)

TABLE 6-12. CONCENTRATIONS OF ASBESTOS FIBERS OCCURRING IN WATER AT LIMESTONE MINES (All concentrations are expressed in units of million fibers per liter) (Continued)

Site and Sampling Point	Total Fibers (all sizes)	Chrysotile Fibers (all sizes)	Total Fibers (restricted sizes)*	Chrysotile Fibers (restricted sizes)*	Detection Limit
France Stone Co. Bloomville Quarry					
1. Pit Discharge	0.56	ND	ND	ND	0.07
Flintkote Stone Products Co. (July 24)					
2. Settling Pond Effluent	2.1	0.14	ND	ND	0.07
4. Frother Detention Pond[1]	7.7	0.35	ND	ND	0.35
6. Pit Discharge	50.74	ND	ND	ND	0.43

*Restricted sizes are fibers less than 0.5 mm in diameter and greater than 5 mm in length.

ND - None Detected

[1] Calcite frother operations are not typically present at limestone crushing and washing facilities.

TABLE 6-13. FT. CALHOUN STONE CO.
FT. CALHOUN, NEBRASKA
DECEMBER 17-18, 1979
RECEIVING STREAM - MISSOURI RIVER

Station	Depth (meters)	Temperature (°Centigrade)	Conductivity (mmhos/cm)	Dissolved Oxygen (ppm)	pH	ORP (mv)	Total Suspended Solids[1] (mg/l)
002[2]	-	-	-	-	-	-	<10
004[2]	-	-	-	-	-	-	28
Missouri River (upstream of quarry)[3]							21

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[1] Hach method (photometric).

[2] Measurements of 002 and 004 waters were not made because these streams are short, man-made ditches with little biota.

[3] Measurements of Missouri River waters were not made because the size of this river made detailed assessment of impacts infeasible.

6.2.2 River City Products

The River City Products quarry has one discharge into the Iowa River. Planktonic, benthic and water samples were taken above and below the outfall. Dissolved oxygen, conductivity, temperature and total suspended solids were not significantly different above and below the outfall (Table 6-14). Plankton above and below the outfall were also similar. The phytoplankton was dominated by a diatom, Asterionella formosa. Other species of phytoplankton included Tabellaria sp., Nitzschia spp., Stephanodiscus sp., Cyclotella sp., and an unidentified euglenoid. Zooplankton was sparse and consisted mainly of a rotifer, Keratella, with a minor component of an unidentified cladoceran.

The TSS of the discharge of 11 mg/l was lower than that of the Iowa River. This discharge is often of higher quality than the Iowa River (Table 6-15), and no adverse impacts to the river were found or are expected at current levels and quality of discharge.

6.2.3 The Stone Man, Inc.

The quarry's combined pit and washing wastes are discharged to a small drainage ditch which empties into Dry Creek. The creek immediately upstream from the discharge had a total suspended solids load of less than 10 mg/l (Table 6-16) while the drainage ditch had a total suspended solids load of 465 mg/l. The downstream combined TSS load was 130 mg/l. This is an order of magnitude increase in the sediment load of Dry Creek as the discharge from the Stone Man joins it. Conductivity also rises in the creek from 0.19 mmhos/cm above the ditch to 0.23 below the ditch. Dry Creek was visibly affected by the discharge but no biological effects were evident.

TABLE 6-14. RIVER CITY PRODUCTS
IOWA CITY, IOWA
DECEMBER 19, 1979
RECEIVING STREAM - IOWA RIVER

Station	Depth (meters)	Temperature (°Centigrade)	Conductivity (mmhos/cm)	Dissolved Oxygen (ppm)	pH	ORP (mv)	Total Suspended Solids[1] (mg/1)
Iowa River Upstream of Quarry	Surface	2.1	.223	6.35	--[2]	--[2]	11
Iowa River Downstream of Quarry	Surface	2.2	.230	6.27	--[2]	--[2]	11

[1] Hach method (photometric)

[2] Equipment malfunction

TABLE 6-15. SUSPENDED SEDIMENTS OF THE IOWA RIVER AND CONKLIN QUARRY EFFLUENT*

	Total Suspended Sediment (mg/l)	
Date	Iowa River (At Quarry Water Intake)	Quarry Discharge
8/31/80	50	18
9/25/80	20	12
11/26/80	34	11

*River City Products Data.

TABLE 6-16. THE STONE MAN, INC.
CHATTANOOGA, TENNESSEE
JANUARY 24, 1980
RECEIVING STREAM - DRY CREEK

Station	Depth (meters)	Temperature (°Centigrade)	Conductivity (mmhos/cm)	Dissolved Oxygen (ppm)	pH	ORP (mv)	Total Suspended Solids[1] (mg/l)
Drainage ditch from plant	0.3	7.8	0.30	10.85	8.79	314	465
Upstream of discharge on Dry Creek	0.4	9.0	0.19	10.65	8.30	326	<10
Partial mixing zone	0.9	8.5	0.21	10.69	8.49	322	222
Upstream of discharge point (backwash)	0.5	9.0	0.19	10.60	8.32	323	16
Downstream of discharge point (in mixed region)	0.5	8.8	0.23	10.50	8.50	312	130
Pit	0.6	7.5	0.40	11.72	8.89	258	45

[1] Hach method (photometric)

There were no phytoplankton or zooplankton in the creek at the site. Macrophytic algae consisted of mats of Cladophora sp. heavily epiphytized by Cocconeis sp., with a few colonies of Synedra sp. Some chains of Melosira sp. were also found intertwined with the Cladophora. The Cocconeis sp. epiphyte occurred on stands of Cladophora sp. both above and below the drainage ditch outfall. Either the sediment addition from this ditch was temporary or it does not affect either the Cladophora sp. or Cocconeis sp. Most probably it was a temporary addition.

The only benthic invertebrate found in Dry Creek was a decapod crustacean Orconectes sp.

6.2.4 Southern Stone Co.

This quarry discharges to an unnamed creek. The quarry pond is the headwater of the creek, but at the time of our visit, the creek was dammed. The dried bed of the creek was covered with the remnants of last year's bloom of duckweed (Lemna sp.). A second drainage ditch runs by the perimeter of the plant and receives some discharge from the washing operation.

The pond on the quarry site had a relatively high pH (Table 6-17) and had a flora typical of hardwater. The dominant aquatic plant was Chara sp., a member of the Charophyta characteristic of hard waters. Alga mats near the perimeter of the pond were composed of Ulothrix sp., Spirogyra sp., and Zygnema sp., filamentous green algae typical of mildly eutrophic still waters. Phytoplankton was sparse. The diatom Nitzschia sp. and the euglenoid Euglena sp. were present. The benthic fauna was composed of Odonata, dragonfly and damselfly nymphs. In the Zygoptera (damselfly nymphs) both Erythodiplax sp. and Perithemis occurred. The Anisoptera (dragonflies) were represented by Gynacantha sp.

TABLE 6-17. SOUTHERN STONE COMPANY
BIRMINGHAM, ALABAMA
JANUARY 25, 1980
RECEIVING STREAM - UNNAMED

Station	Depth (meters)	Temperature (°Centigrade)	Conductivity (mmhos/cm)	Dissolved Oxygen (ppm)	pH	ORP (mv)	Total Suspended Solids[1] (mg/1)
Pit discharge	0.5	10.6	0.44	10.50	8.51	316	4.0
Lake (near previous discharge)	0.5	11.0	0.57	10.42	8.68	310	8.8

[1] Gravimetric method

Quarry workers reported that the pond supported bass, bluegills and catfish and that the pond was fished regularly.

6.2.5 Flintkote Stone Products, 13 February 1980

The Flintkote quarry discharges calcite mine, froth flotation, physical plant, and settled washing effluents into Goodwin Run, a tributary of Beaver Dam Run. Beaver Dam Run empties directly into Loch Raven Reservoir, the primary source of drinking water for the city of Baltimore. Upstream from the quarry, Goodwin Run is cobble and gravel bottomed, downstream there is a noticeable sediment, apparently finely divided calcite, covering the cobble.

Suspended sediment loads in Goodwin Run at the time of this sampling increased slightly as the creek passed through the quarry. Upstream values were 15 mg/l TSS while below the 880 settling pond the TSS was 18 mg/l. Conductivity increased significantly from 0.27 mmhos/cm upstream to 0.46 mmhos/cm downstream (Table 6-18).

There was a pronounced change in the periphytic and attached algal flora as the creek passed through the quarry. Upstream from the quarry the algal community was dominated quite strongly by the chain forming diatom, *Diatoma* sp. The diatom community associated with the *Diatoma* was composed of a tube-forming *Cymbella* sp., chain-forming *Melosira* sp. and tufts of *Synedra* sp. with interspersed *Nitzschia* sp. This abundant diatom flora was completely replaced downstream of the froth flotation outfall by a flora dominated by *Cladophora* sp., a filamentous green alga, some species of which are characteristic of stressed communities. Most species of the periphytic diatom community were encountered in the plankton downstream. The cause

TABLE 6-18. FLINTKOTE STONE PRODUCTS, TEXAS QUARRY
COCKEYSVILLE, MARYLAND
FEBRUARY 13-14, 1980
RECEIVING STREAM - GOODWIN RUN

Station	Depth (meters)	Temperature (°Centigrade)	Conductivity (mmhos/cm)	Dissolved Oxygen (ppm)	pH	ORP (mv)	Total Suspended Solids^{1,2} (mg/1)
Goodwin Run upstream from plant	0.3	1.8	0.27	13.95	8.50	292	15^2
Calcite discharge	-	-	-	-	-	-	52^1
At outfall of underground portion of stream	0.3	4.5	0.23	12.52	8.00	239	12^2
Inlet to 880 pond	0.2	5.5	0.80	11.62	8.05	255	355^1
Outlet of 880 pond	-	2.1	0.83	12.85	8.14	254	$<1.0^1$
Goodwin Run below last quarry discharge	0.5	3.9	0.46	12.28	8.97	217	18^2
Beaver Dam Run below confluence with Goodwin Run	0.6	3.1	0.16	12.52	7.65	288	10^2

[1] Gravimetric method

[2] Hach method (photometric)

of the shift in communities is undetermined, however heavy coatings of sediment were found on the downstream stands of Cladophora (Figure 6-1) while this sediment was absent upstream.

The benthic fauna of the upstream reaches of Goodwin Run was composed mainly of Tendipes sp. larvae. Goodwin Run below the last quarry discharge has a shifting sand bottom and the Tendiped fauna was absent. No other macroinvertebrates were found in the winter collections.

6.2.6 Oldham Stone Co.

The Oldham Stone Co. quarry discharges into an unnamed tributary of Harrod's Creek. At the time of sampling the quarry was discharging pit dewatering only.

There was a rise in total suspended solids from 4.0 mg/l above the discharge to 25 mg/l below the discharge (Table 6-19). Conductivity also rose from 0.19 mmhos/cm above the discharge to 0.65 mmhos/cm directly below the discharge. The algae of the tributary were characterized by a Diatoma/Stigeoclonium flora (Table 6-20).

Diatoma is a periphytic chain-forming diatom. Stigeoclonium is a much branched filamentous green alga characteristic of eutrophic waters. There was no detectable difference between the flora upstream from the quarry outfall and that found downstream.

Benthic invertebrates consisted of Oligochaetes, Caddisfly larvae and Tendiped larvae; no differences in benthic fauna were noted between stations above the quarry outfall and stations below the outfall.

Figure 6-1. Flintkote Stone Products Co., Texas Quarry. Cladophora sp. Covered with Sediment Immediately Upstream of Sedimentation Pond 380 Discharge

TABLE 6-19. OLDHAM STONE COMPANY
LOUISVILLE, KENTUCKY
FEBRUARY 28, 1980
RECEIVING STREAM - TRIBUTARY TO HARROD'S CREEK

Station	Depth (meters)	Temperature (°Centigrade)	Conductivity (mmhos/cm)	Dissolved Oxygen (ppm)	pH	ORP (mv)	Total Suspended Solids[1] (mg/l)
Upstream of pit discharge	0.3	5.1	0.19	12.90	9.05	176	4.0
Downstream of pit discharge	0.2	6.9	0.65	10.85	8.15	246	25
Harrod's Creek upstream of confluence with tributary	0.2	8.4	0.39	12.25	8.43	245	-
Harrod's Creek downstream of confluence with tributary	0.3	7.8	0.50	11.29	8.33	249	22

---

[1] Gravimetric method

TABLE 6-20. ALGAE OF THE UNNAMED TRIBUTARY TO HARROD'S CREEK - FEBRUARY 28, 1980

- Bacillariophyta (diatoms)
  - Diatoma sp. (codominant)
  - Cymbella sp. (subdominant)
  - Tabellaria sp.
  - Nitzschia sp.
  - Nitzschia sp. (bicapitate)
  - Campylodiscus
  - Rhoicosphenia curvata
  - Amphora sp.
  - Cocconeis sp.
  - Surirella sp.

- Chlorophyta (green algae)
  - Stigeoclonium sp. (filamentous codominant)
  - unidentified volvocalean alga

- Cyanochloronta (blue green algae)
  - Nodularia sp.
  - Gloeocapsa sp.

6.2.7 Kentucky Stone Company

The Kentucky Stone Company quarry effluent is composed of pit discharges only. There is no discharge from the crushing operation. Discharge is to an unnamed drainage ditch. The ditch is ephemeral, and at the time of sampling was running due to recent rainfall. Phytoplankton was composed of *Cocconeis* sp., *Opephora* sp., and *Navicula* sp., all diatoms. An unidentified tintinnid was also present in the plankton. Total suspended sediment in the stream was 18 mg/ℓ (Table 6-21).

6.2.8 France Stone Company, Monroe, Michigan

The France Stone Company quarry discharges to Plum Creek. The creek was apparently heavily loaded with agricultural and urban loadings at the time of sampling. Water quality measurements were made at four upstream stations, at the discharge point, and at one station downstream from the quarry discharge. Conductivity rose as one progressed downstream (Table 6-22). Total suspended solids increased slightly at the downstream stations; the pit discharge, however, had a lower sediment load than Plum Creek upstream of the discharge.. The discharge increased the dissolved oxygen in Plum Creek.

The biota of the stream were typical of eutrophic midwest streams. The algal community was completely dominated by *Cladophora* sp., a filamentous green alga. The diatoms, *Cocconeis* sp., *Gyrosigma* sp. and numerous species of *Nitzschia* also occurred. The *Cladophora* was covered with a stalked diatom, *Cymbella*.

The benthic invertebrate community was dominated by the bloodworm, *Tendipes* sp.; leeches, *Macrobdella sp*.; freshwater limpets, *Ferrissia sp*.; clams, *Sphaerium sp*.; snails *Ammicola sp*.;

TABLE 6-21. KENTUCKY STONE COMPANY
TODD CO. QUARRY
ELKTON, KENTUCKY
FEBRUARY 29, 1980
RECEIVING STREAM - UNNAMED

Station	Depth (meters)	Temperature (°Centigrade)	Conductivity (mmhos/cm)	Dissolved Oxygen (ppm)	pH	ORP (mv)	Total Suspended Solids[1] (mg/1)
Receiving Stream[2]	-	-	-	-	-	-	18

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[1] Hach method (photometric)

[2] Measurements of receiving stream were not made because the stream is a man-made ditch with little biota.

TABLE 6-22. FRANCE STONE COMPANY
MONROE, MICHIGAN
MAY 12-13, 1980
RECEIVING STREAM - PLUM CREEK

Station	Depth (meters)	Temperature (°Centigrade)	Conductivity (mmhos/cm)	Dissolved Oxygen (ppm)	pH	ORP (mv)	Total Suspended Solids[1,2] (mg/1)
Strasburg Road Bridge (upstream of discharge)	0.1	14.3	0.70	6.15	7.57	309	10[2]
Rasinville Road Bridge (upstream of discharge)	0.3	14.2	0.84	7.07	7.65	310	12[2]
Herr Road Bridge (upstream of discharge)	0.2	13.9	0.88	6.22	7.74	306	12[2]
M 125 Bridge (upstream of discharge)	0.3	14.2	1.07	6.61	7.75	288	13[2]
Pit Discharge	0.1	17.2	1.08	11.58	8.20	244	3.1[1]
LaPlaisance Road Bridge (downstream of discharge)	0.1	15.3	1.04	9.96	8.15	265	13[2]

---

[1] Gravimetric method

[2] Hach method (photometric)

and an unidentified isopod were also found.

6.2.9 France Stone Company, Bloomville, Ohio

The France Stone Company quarry at Bloomville, Ohio empties into Eicholtz Creek. On the day of sampling, the creek was turbid because of recent rains. Total suspended solids ranged from 65 mg/l immediately above the quarry discharge to 76 mg/l below the discharge (Table 6-23). This increase in suspended sediments may be because of bottom scour. As in most cases, conductivity increased downstream from the quarry outfall. As a measure of nutrient level, both phosphates and nitrates of the outfall and receiving stream were measured. In both cases of phosphate and nitrate, the limestone quarry effluents were lower than the creek and significantly lowered levels of both nutrients in the creek.

Very little plankton was found at the site, composed mainly of *Tabellaria* sp., *Navicula* sp., *Pleurosigma* sp., and *Oscillatoria* sp. The blue-green alga *Oscillatoria* was the dominant form.

The upstream invertebrates consisted of bloodworm larvae (*Tendipes* sp.), Limnephilid caddis fly larvae and the clam *Unio* sp. Downstream invertebrates were characterized by a similar fauna with the addition of mosquito larvae (*Culex* sp.)

6.2.10 Flintkote Stone Products, 24 July 1980

On this date, Goodwin Run was turbid because of a recent rain. Total suspended solids ranged from 9.0 mg/l to 10

TABLE 6-23. FRANCE STONE COMPANY
BLOOMVILLE, OHIO
JULY 23, 1980
RECEIVING STREAM - EICHOLTZ DITCH

Station	Depth (meters)	Temperature (°Centigrade)	Conductivity (mmhos/cm)	Dissolved Oxygen (ppm)	pH	ORP (mv)	Total Suspended Solids[1],[2] (mg/l)	Phosphates (mg/liter) Total	Phosphates (mg/liter) Ortho	Nitrates (mg/liter)
Highway 8 Bridge upstream of discharge	intermittent pools									
Highway 4 Bridge upstream of discharge	0.4	20.2	0.28	3.12	6.53	169	-	-	-	-
Highway 58 Bridge upstream of discharge	0.4	21.4	0.32	5.48	6.95	265	-	-	-	-
Highway 23 Bridge upstream of discharge	0.4	21.1	0.34	5.65	3.13	276	-	-	-	-
Highway 77 Bridge upstream of discharge	0.2	21.2	0.32	5.91	7.28	282	-	-	-	-
Quarry Pit	0.0	28.5	0.83	7.98	8.36	274	-	-	-	-
Upstream from Outfall	0.3	21.8	0.32	6.06	7.33	239	65[1]	.44	.15	12
Outfall	0.2	20.0	0.89	8.45	7.90	091	5.0[1]	.11	<.01	4.0
Mixing Zone downstream of discharge	0.5	21.8	0.34	6.18	7.38	233	75[1]	.22	.04	5.1
Downstream of mixing zone	0.4	21.7	0.40	6.52	7.43	199	76[1]	.37	-[3]	9.9
Highway 49 Bridge downstream of discharge	0.5	21.0	0.41	6.20	7.60	292	-	-	-	-

[1] Gravimetric method

[2] Hack method (photometric)

[3] Sample destroyed

mg/ℓ, an insignificant increase as the creek passed the quarry (Table 6-24). Conductivity in Goodwin Run was increased by the quarry discharge from a value of 0.24 mmhos/cm above the quarry to 0.70 mmhos/cm below the quarry. Phosphates and nitrates in the creek were measured to determine if the quarry was adding to the nutrient load of the creek. There was a significant increase in nitrates in Goodwin Run below the quarry; which was unexplained. Possibly there were unnoticed sanitary loadings.

The plankton of the creek were characteristic of mildly eutrophic conditions, dominated by blue-green algae (*Arthrospira* sp., and *Oscillatoria* sp.), volvocalean green alga (*Pandorina* sp.) and euglenoids (*Phacus* sp.). The diatoms *Tabellaria* sp., *Cymbella* sp., *Navicula* sp., *Surirella* sp., and *Cocconeis* sp. were also found. The desmid *Closterium* sp. occurred in one downstream sample. Zooplankton was composed mainly of Ostracods and Tintinnids. The dominant alga at downstream stations was the pollution-tolerant green alga *Stigeoclonium* sp.

Benthic fauna consisted of bloodworm larvae, *Tendipes* sp.; clams *Psidium* sp.; and snails, *Viviparous* sp. Numerous water striders, *Gerris* sp., were also found.

TABLE 6-24. FLINTKOTE STONE PRODUCTS COMPANY, TEXAS QUARRY
COCKEYSVILLE, MARYLAND
JULY 24, 1980
RECEIVING STREAM - GOODWIN RUN

Station	Depth (meters)	Temperature (°Centigrade)	Conductivity (mmhos/cm)	Dissolved Oxygen (ppm)	pH	ORP (mv)	Total Suspended Solids[1] (mg/l)	Phosphates (mg/liter) Total	Phosphates (mg/liter) Ortho	Nitrates (mg/liter)
Goodwin Run up-stream from plant	0.2	26.5	0.24	8.86	8.88	262	9.0[1]	.17	<.01	2.9
Calcite Discharge below discharge; discharge not active	0.0	25.2	0.20	8.18	8.43	267	11	.18	.03	2.6
Entrace to under-ground portion of stream	0.2	25.4	0.37	9.13	8.67	230	-	-	-	-
Outfall of under-ground portion of stream	0.4	21.3	0.41	7.68	8.16	239	-	-	-	-
Outlet of 880 pond	0.2	25.2	0.85	8.63	815.	259	13[1]	-	-	-
Goodwin Run below last quarry dis-charge	0.4	23.3	0.70	8.94	8.48	296	10	<.01	<.01	8.7

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[1] Gravimetric method

7.0 EFFECTS OF DISCHARGES

7.1 Water Quality Effects

As reported in Section 6, water quality samples were collected from limestone quarries and processing plants across the nation. These samples were analyzed for suspended and dissolved solids, silica, hardness, turbidity and pH. Concentrations of lead, mercury, nickel, chromium, cadmium, selenium, zinc, and iron were also determined. In addition, samples were collected and analyzed for asbestos.

The physical characteristics of the samples collected are summarized in Table 6-2 by type of discharge (i.e., untreated washing wastewater, sedimentation pond effluent, and pit dewatering discharges). As reported in Section 6.1, water quality varied significantly at different points within the process flow stream.

In this section, the water quality effects of each constituent are discussed in general, followed by a discussion of the effects of each constituent as found in limestone effluents in particular. The discussion of general effects is essentially a literature review, and effects of limestone effluents are evaluated based on information obtained from this review.

The water quality effects of treated wastewater (sedimentation pond effluents), untreated wastewater (washing wastewater before sedimentation), and pit water are examined. The effects of untreated wastewater are included in the discussion as a potential discharge, although such discharges are not permitted by the National Pollution Discharge Elimination System (NPDES). Practically all mines and washing operations now employ wastewater treatment systems as a result of the NPDES requirements. The effects of untreated wastewater were included in the study to determine the effect of no NPDES requirements.

These effects of untreated wastewater on receiving streams are derived from the literature.

Water quality effects include both beneficial and detrimental effects. In many instances, the discussion describes effects without referring to them as either beneficial or detrimental, although some beneficial and detrimental effects are noted.

7.1.1 Suspended Solids and Turbidity

General Effects

Total suspended solids (TSS) are the non-filterable residue (particle sizes above 0.8 micron) remaining after evaporation at 103° to 105°C (APHA, 1976). Suspended solids may consist of either organic or mineral matter. Mineral suspended solids, such as those found in limestone wastewater, do not decompose and deplete the dissolved oxygen in the stream, although they may cause other minor types of undesirable effects.

Turbidity is closely related to suspended solids and will therefore be discussed in this section. Although there is not an exact relationship, correlations have been observed between TSS and turbidity (Delfino, 1977). Turbidity is an expression of the optical properties of water and depends on both the concentration and composition of particles in the sample (APHA, 1976).

Suspended solids settling from the water column can blanket the streambed causing harm to benthic organisms. This problem, as well as the effects of solids in the water column on fish and wildlife, will be discussed in Section 7.2 on Biology.

Suspended solids adsorb and transport other constituents such as pesticides and nutrients (NAS, 1972; Robinson, 1971; Brashier, 1973; Klages, 1974). Agricultural lands are a major source of suspended solids in the form of sediment runoff, and pesticides and nutrients are generally associated with this source of sediment runoff.

Suspended solids interfere with domestic water supplies. The need to remove the suspended solids results in increased treatment costs. Turbidity, which is indirectly related to suspended solids concentrations, is limited in water supplies by the National Interim Primary Drinking Water Regulations to a maximum monthly average of one turbidity unit. This limit for turbidity is not only desirable for clarity of the drinking water, but is also desirable because suspended solids decrease the effectiveness of disinfectants by protecting organisms from proper contact with the disinfectant (Metcalf and Eddy, Inc., 1979).

Suspended solids in industrial water supplies also require costly treatment. Suspended solids and turbidity must be limited not only in consumptive products (beverages, food products, ice), but in other industrial processes such as boiler feed, cooling water, pulp and paper, textiles, petroleum refining, and tanning (NAS, 1972). Table 7-1 presents water quality characteristics of water which have been used as sources for industrial water supplies.

TABLE 7-1. SUMMARY OF SPECIFIC QUALITY CHARACTERISTICS OF SURFACE WATERS THAT HAVE BEEN USED AS SOURCES FOR INDUSTRIAL WATER SUPPLIES (Unless otherwise indicated, units are mg/l and values are maximums. No one water will have all the maximum values shown.)

Characteristics	Boiler Makeup Water		Cooling Water				Process Water										
			Fresh		Brackish[a]								Mining Industry		Oil Recovery Injection Waters	
	Industrial 0 to 1,500 psig	Utility 700 to 5,000 psig	Once Through	Makeup Recycle	Once Through	Makeup Recycle	Textile Industry SIC-22	Lumber Industry SIC-24	Pulp and Paper Industry SIC-26	Chemical Industry SIC-28	Petroleum Industry SIC-29	Prim. Metals Industry SIC-33	Copper Sulfide Concentrator Process Water	Copper Leach Solution	Sea Water	Formation Water
Silica (SiO$_2$)	150	150	50	150	25	25	......	......	50	......	85					
Aluminum (Al)	3	3	3	3	......	......	......	......	......	......	......	......	......	12,000		
Iron (Fe)	80	80	14	80	1.0	1.0	0.3	......	2.6	10	15	......	......	12,000[g]	0.2	13
Manganese (Mn)	10	10	2.5	10	0.02	0.02	1.0	......	......	2						
Copper (Cu)	......	......	......	......	......	......	0.5									
Calcium (Ca)	......	......	500	500	1,200	1,200	......	......	......	250	220	......	1,510 (CaCO$_3$)	......	400	2,737
Magnesium (Mg)	......	......	......	......	......	......	......	......	......	100	85	......	......	12,000	1,272	655
Sodium & potassium (Na+K)	......	......	......	......	......	......	......	......	......	......	230	......	......	......	10,840	42,000
Ammonia (NH$_3$)	......	......	......	......	......	......	......	......	......	......	40					
Bicarbonate (HCO$_3$)	600	600	600	600	180	180	......	......	......	600	480	......	......	......	142	283
Sulfate (SO$_4$)	1,400	1,400	680	680	2,700	2,700	......	......	......	850	900	......	1,634	64,000	2,560	42
Chloride (Cl)	19,000	19,000	600	500	22,000	22,000	......	......	200[b]	500	1,600	500	13	......	18,980	72,782
Fluoride (F)	......	......	......	......	......	......	......	......	......	......	1.2					
Nitrate (NO$_3$)	......	......	30	30	......	......	......	......	......	......	8					
Phosphate (PO$_4$)	......	50	4	4	5	5										
Dissolved solids	35,000	35,000	1,000	1,000	35,000	35,000	150	......	1,080	2,500	3,500	1,500	2,100	......	34,292	110,124
Suspended solids	15,000	15,000	5,000	15,000	250	250	1,000	c	......	10,000	5,000	3,000				
Hardness (CaCO$_3$)	5,000	5,000	850	850	7,000	7,000	120	......	475	1,000	900	1,000	1,520			
Alkalinity (CaCO$_3$)	500	500	500	500	150	150	......	......	......	500	500	200	415			
Acidity (CaCO$_3$)	1,000	1,000	0	200	0	0	......	......	......	......	......	75				
pH, units	......	......	5.0-8.9	3.5-9.1	5.0-8.4	5.0-8.4	6.0-8.0	5-9	4.6-9.4	5.5-9.0	6.0-9.0	3-9	to 11.7	3-3.5	......	to 6.5
Color, units	1,200	1,200	......	1,200	......	......	......	......	360	500	25					
Organics:																
Methylene blue active substances	2[d]	10	1.3	1.3	......	1.3										
Carbon tetrachloride extract	100	100	e	100	e	100	......	......	......	......	......	30				
Chemical oxygen demand (COD)	100	500	......	100	......	200										
Hydrogen sulfide (H$_2$S)	......	......	......	......	4	4	......	......	......	......	20					
Temperature, F	120	120	100	120	100	120	......	......	95[f]	......	......	100				

[a] Water containing in excess of 1,000 mg/l dissolved solids.
[b] May be <1,000 for mechanical pulping operations.
[c] No particles ≥3 mm diameter.
[d] One mg/l for pressures above 700 psig.
[e] No floating oil.
[f] Applies to bleached chemical pulp and paper only.
[g] 12,000 mg/l Fe includes 6,000 Fe^{2+} and 6,000 Fe^{3+}.
ASTM Standards 1970 or Standard Methods 1971.

Source: Water Quality Criteria, 1972.

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When suspended solids concentration and turbidity are high, recreational uses of water bodies are impacted. Swimming and diving become hazardous when visibility in the water is reduced, and the aesthetic attractiveness of water also decreases. When fish and wildlife are impacted (Section 7.2), non-contact recreation such as fishing is likewise effected.

Another effect of suspended solids in natural waters is the physical effect upon channels and impoundments, although such effects are caused primarily by sediment runoff and transport. Settling of solids causes aggradation of streambeds and filling of impoundments which results in interference with navigation, increased flooding, and loss of storage capacity (University of Pittsburgh, 1972). In certain cases, costly dredging is required to improve such conditions. Lakes and impoundments may also have an increased eutrophication potential due to nutrients associated with suspended solids which are entering the lake.

TSS and Turbidity in Limestone Effluents

Total suspended solids (TSS) and turbidity varied considerably between points within the process flow stream, specifically before and after sedimentation of stone washing wastewater. Table 7-2 below summarizes the results for TSS and turbidity for samples collected during this study. The effects of these two types of wastewaters (treated and untreated) will be discussed in this section.

The concentrations of suspended solids found in sedimentation pond effluents and pit dewatering discharge should have a minimal effect on water quality of receiving streams. The suspended solids would tend to settle in the receiving stream, but the settling rate is dependent on the velocity and turbulence

TABLE 7-2. SUMMARY OF RESULTS OF TSS AND TURBIDITY ANALYSES

Type of Sample	TSS (mg/l) Range	TSS (mg/l) Median	Turbidity (FTU) Range	Turbidity (FTU) Median
Sedimentation Pond Effluent	<1 - 13.0	5	1 - 12	9.0
Pit Dewatering Discharge	<1 - 62.0	3.7	<1 - 16	1.5
Untreated Washing Wastewater	168 - 16,000	4,100.0	32 - >250	>250.0

of the stream, as well as the settling velocity of the particles. After passing through sedimentation ponds, the effluent would probably contain only the smaller, slower settling solids, which would probably not settle immediately at the outfall point, but would generally be more distributed in the downstream directions.

The turbidity levels in the sedimentation pond effluents and pit discharges are within the range of turbidities reported for natural waters. Average turbidities in thirteen major rivers across the United States ranged from 2.5 to 56.8 JTU in 1977 (CEQ, 1979). In addition, at four of the five quarries visited where stream quality was available, TSS values in the receiving streams upstream of the discharge points were higher than the TSS values in the sedimentation pond effluents and pit discharges.

Therefore, since effluents were at or below concentrations of TSS found in natural water, sedimentation pond and pit dewatering discharges generally should not cause cost increases to municipalities treating water to reduce suspended solids and turbidity for public water supplies.

Similarly, low levels of TSS and turbidity from sedimentation ponds and pits would probably not effect industrial, agricultural or recreational water uses, since the effluent concentrations are within the range of typical concentrations of natural water.

The concentrations of suspended solids found in washing wastewater before entering sedimentation ponds would have a significant effect on receiving stream water quality if discharged without further treatment, although such discharges currently are not permitted. At the TSS and turbidity levels summarized in Table 7-2 for untreated washing wastewater, the physical effects on the streambed, pools, or impoundments would be more pronounced than for sedimentation pond effluent. The effects on various water users would be unacceptable in many cases.

If untreated washing wastewater were discharged directly to a receiving stream, a large percentage of the suspended solids would settle to the streambed immediately downstream of the discharge point. The first pool below the outfall would function essentially as a sedimentation pond for suspended solids remaining in the water at that point. Detrimental effects to the biological communities resulting from such conditions are discussed in Section 7.2. Other effects include loss of channel capacity and impoundment storage and the resuspension of solids during high flow events (Delfino, 1977).

The extent to which water uses would be effected by a discharge of untreated suspended solids would depend on factors such as the amount of dilution provided by the receiving stream, the distance of the desired use downstream of the discharge point, and the type of water use being considered.

In cases where a stream is a source of a water supply for either municipal or industrial uses, it is generally implied that there is sufficient flow to provide dilution of a limestone process wastewater discharged to that stream. Also, since suspended solids would tend to settle in the stream, the effect of suspended solids would be decreasing in the downstream direction. Therefore, the effect on water supplies of a discharge of suspended solids would probably be less significant than the physical impacts to the stream near the discharge point. However, the potential exists for water supplies to be effected if they are located near the point of discharge of untreated limestone wastewaters and during high flow periods when the settled solids could be resuspended.

Suspended solids concentrations in untreated limestone process wastewaters could potentially effect agricultural water uses, depending on the proximity to the discharge point and the amount of dilution provided by the receiving stream. Soils irrigated with high TSS waters could be effected by the formation of a surface layer, which could reduce infiltration and decrease soil aeration (NAS, 1972). Leafy crops could be coated with a silty film making them less marketable. In addition, irrigation water storage ponds and stock watering tanks downstream of a limestone discharge could be filled with sediment much more rapidly than under natural conditions.

Finally, recreation areas located downstream of a discharge of untreated process wastewater would probably become less attractive and desirable because of streambed aggradation and pool sedimentation.

7.1.2 Dissolved Solids

General Effects

Total dissolved solids (TDS) are the remaining residue upon evaporation of a filtered sample at 103 to 105°C. Dissolved solids consist mainly of inorganic salts, small amounts of organic matter, and dissolved gases (APHA, 1976).

High levels of TDS are objectionable primarily in municipal and irrigation water supplies. The National Secondary Drinking Water Regulations established a limit of 500 mg/l of total dissolved solids for public water systems. Objectionable tastes increase with increasing concentrations of TDS, and, for high levels of TDS, there may be a laxative effect, particularly upon transients. High concentrations of mineral salts (particularly sulfate and chloride) are associated with costly corrosion damage in water systems (NAS, 1972).

Dissolved solids can reduce productivity and have a detrimental effect on crops at high levels. Table 7-3 describes the effects of TDS at various levels.

TABLE 7-3. RECOMMENDED GUIDELINES FOR SALINITY IN IRRIGATION WATER

Classification	TDS mg/l
Water for which no detrimental effects are usually noticed	500
Water that can have detrimental effects on sensitive crops	500-1,000
Water than can have adverse effects on many crops; requires careful management practices	1,000-2,000
Water that can be used for tolerant plants on permeable soils with careful management practices	2,000-5,000

Source: Water Quality Criteria, 1972, National Academy of Sciences, National Academy of Engineering

Water used as a supply for livestock can create problems and, at very high levels, be completely unsuitable for use as stock water (NAS, 1972). Table 7-4 summarizes the guidelines for use of saline waters for livestock watering.

Industrial and commercial water supplies may be effected by dissolved solids, depending on the process and product. Table 7-1 (presented previously) includes dissolved solids concentrations which have been used by various industries.

Total Dissolved Solids in Limestone Effluents

The following table summarizes the concentrations of TDS at various points in the process flow stream at limestone processing plants.

TABLE 7-5. SUMMARY OF RESULTS OF TDS ANALYSES

	TDS mg/l	
Type of Sample	**Range**	**Median**
Sedimentation Pond Effluent	223 - 467	299
Pit Dewatering Discharge	231 - 1,800	613
Untreated Washing Wastewater	397 - 9,600	490

The TDS concentrations in the effluents from sedimentation ponds sampled is less than the drinking water standards (500 mg/l), and is at excellent levels for agriculture and most industrial uses.

TABLE 7-4. GUIDE TO THE USE OF SALINE WATERS FOR LIVESTOCK AND POULTRY

Total Soluble Salts Content of Waters (mg/l)	Comment
Less than 1,000	Relatively low level of salinity. Excellent for all classes of livestock and poultry.
1,000- 2,999	Very satisfactory for all classes of livestock and poultry. May cause temporary and mild diarrhea in livestock not accustomed to them or watery droppings in poultry.
3,000- 4,999	Satisfactory for livestock, but may cause temporary diarrhea or be refused at first by animals not accustomed to them. Poor waters for poultry, often causing water feces, increased mortality, and decreased growth, especially in turkeys.
5,000- 6,999	Can be used with reasonable safety for dairy and beef cattle, for sheep, swine, and horses. Avoid use for pregnant or lactating animals. Not acceptable for poultry.
7,000-10,000	Unfit for poultry and probably for swine. Considerable risk in using for pregnant or lactating cows, horses, or sheep, or for the young of these species. In general, use should be avoided although older ruminants, horses, poultry, and swine may subsist on them under certain conditions.
Over 10,000	Risks with these highly saline waters are so great that they cannot be recommended for use under any conditions

Source: Water Quality Criteria, 1972, National Academy of Sciences, National Academy of Engineering

Several of the pit dewatering discharges sampled contained TDS concentration above the drinking water standard. The median value observed was 613 mg/l. The pit water is primarily made up of ground-water seepage into the pit and the TDS levels observed are probably the natural ground-water quality.

The TDS concentrations reached very high levels in the untreated washing wastewater at one facility visited. However, the median value for all samples was below the drinking water standard of 500 mg/ℓ. The potential effects of these levels depend to a great extent upon the amount and quality of dilution water in the receiving streams. Where there is even a small amount of dilution available, water users should not be significantly effected by the levels of TDS measured at these limestone facilities.

7.1.3 Hardness

General Effects

Hardness is the sum of the polyvalent cations and is usually expressed as the equivalent quantity of calcium carbonate. The most common cations of hardness are calcium and magnesium. In general, these ions in public water supply sources are not cause for concern to health, although there are some indications that hardness may effect the tolerance of some organisms to other metal ions (NAS, 1972).

Hardness is of concern in domestic and industrial water supplies because of the buildup of scale deposits when the water is heated. Refer to Table 7-1 for hardness levels which have been used in various industrial categories.

Hardness in Limestone Effluents

The concentrations of hardness found in the various limestone quarry and processing plant flow streams are summarized in Table 7-6.

TABLE 7-6. SUMMARY OF RESULTS OF HARDNESS ANALYSES

	Hardness (mg/l as $CaCO_3$)	
	Range	Median
Sedimentation Pond Effluent	158 - 264	219
Pit Dewatering Discharge	150 - 1,272	435
Untreated Washing Wastewater	220 - 1,500	950

The sedimentation pond and pit dewatering discharges contained low to medium levels of hardness. Depending on the site-specific characteristics of receiving streams, these levels would not cause major problems for water users, since water sources for most users would consist of significantly higher streamflows than the wastewater discharge rate. The higher streamflows will provide large amounts of dilution to a given discharge before a water use is encountered.

The untreated washing wastewater had significantly higher levels of hardness than sedimentation pond or pit discharges. There is a greater potential, if discharges were permitted, for such high level of hardness to effect a water supply because a greater volume of dilution would be required to lower the hardness to desirable levels. At these levels, it is more likely that domestic or industrial water users would encounter buildups of scale deposits in their water systems.

7.1.4 Silica

General Effects

Silica or silicon dioxide (SiO_2) occurs naturally especially as quartz and agate and is also found as the cementing agent in sedimentary rocks such as sandstone. Silica ranks next to oxygen in abundance in the earth's crust, and degradation of silica containing rocks results in the presence of silica in natural waters.

The silica content of natural water is most commonly in the 1-30 mg/l range although concentrations as high as 100 mg/l are not unusual. Concentrations exceeding 1,000 mg/l are found in some brackish waters and brines (APHA, 1976).

For some industrial users, high levels of silica in water is undesirable because it forms a scale on equipment. Table 7-1 includes levels of silica in waters which have been used by various industries.

Silica in Limestone Effluents

The levels of silica measured in samples collected at limestone quarries were uniformly low, regardless of the type of process being sampled. Table 7-7 summarizes the results for silica.

TABLE 7-7. SUMMARY OF RESULTS OF SILICA ANALYSES

	Silica (mg/l as SiO_2)	
Type of Sample	**Range**	**Median**
Sedimentation Pond Effluent	0.8 - 8.5	3.3
Pit Dewatering Discharge	0.6 - 11.0	4.8
Untreated Washing Wastewater	0.9 - 9.0	6.6

These levels of silica are in the range of silica concentrations for natural waters and should not result in detrimental effects for water users.

7.1.5 pH

General Effects

The National Secondary Drinking Water Regulations set a range of 6.5 to 8.5 for public water supplies. Waters with pH values outside that range have a higher probability of corrosive action.

pH in Limestone Effluents

The range of pH for all samples taken at limestone quarries and processing plants was 7.34-8.30. These levels of pH are nearly optimum for all uses, including municipal, industrial, and irrigation water supplies and for recreational uses. No treatment for pH adjustment was observed.

A potential beneficial effect of limestone effluents is the buffering capacity, especially in streams impacted by acid mine drainage or acid rain. Limestone quarry discharges would tend to neutralize waters with a low pH, although the degree of neutralization would depend on the dilution ratio of the discharge flow to the stream flow and the buffering capacity of the particular discharge.

7.1.6 Heavy Metals

General Effects

The heavy metals which were analyzed are important water quality parameters due to toxicity and objectionable taste. Lead, mercury, nickel, chromium, cadmium and selenium are all toxic to humans above certain levels. These metals, with the exception of nickel, have been limited to specific maximum concentrations in public water supply system by the National Interim Primary Drinking Water Regulations because of their toxicity. Nickel has had limits recommended for protection of freshwater and marine aquatic life (NAS, 1972).

Undissolved zinc and iron and generally considered nontoxic, but result in objectionable tastes, and iron can stain plumbing fixtures, spot laundry, and accumulate as a deposit in distribution systems (NAS, 1972). Zinc is toxic in solution, and is persistent in sediments. Zinc and iron are included in the National Secondary Drinking Water Regulations because of these undesirable characteristics.

Table 7-8 presents the recommended water quality criteria for the metals which are included in this study.

TABLE 7-8. WATER QUALITY CRITERIA FOR HEAVY METALS

Metal	Criteria (mg/1)	Basis for Inclusion in Quality Criteria
lead	.050	toxicity
mercury	.002	toxicity
chromium	.050	toxicity
cadmium	.010	toxicity
selenium	.010	toxicity
zinc	5.000	taste
iron	.300	taste, nuisance
nickel	.002	minimal risk to organisms
	>.100	hazard to marine organisms

Source: Water Quality Criteria, 1972
EPA-R3-73-033, March 1973

Heavy Metals in Limestone Effluents

As discussed in Section 6.1, the metals concentrations in the various limestone effluents are relatively low. The effects of the heavy metals concentrations measured, especially in sedimentation pond and pit discharges, should not have a significant effect on the water quality of receiving streams or downstream uses. Refer to Table 6-11 for a summary of the heavy metals analyses results. The concentrations of all metals except lead are below the drinking water standards in the effluents from sedimentation ponds and pit discharges. The results of the lead analyses are questionable since the dissolved concentration is greater than the total concentration for the same sample, and that sample is the one concentration of lead which is higher than the drinking water standard.

For samples taken from washing wastewater prior to sedimentation treatment, the dissolved metals concentrations were all less than the drinking water standards (or the 0.1 mg/l criteria for nickel). The maximum total metals concentrations were noteably higher than the dissolved metals for lead, nickel, chromium, zinc and iron. The total concentrations of lead, nickel, chromium and iron were approximately three, two, three and 270 times their criterion, respectively, using the worst case. Although the maximum total iron concentration of 81.0 mg/l is 270 times the drinking water standard of 0.3 mg/l, this standard applies only to the soluble iron, and the maximum dissolved iron concentration in limestone effluents is <.1 mg/l. The total concentrations of the remaining metals (mercury, cadmium, selenium, and zinc) were less than the drinking water standards.

It is noteworthy that the only concentrations above the criteria for the metals were found in the particulate phase of the untreated washing wastewater. It is evident that these particulates settle during treatment (sedimentation) and that concentrations have decreased significantly in the sedimentation pond effluent samples.

7.1.7 Asbestos

General Effects

"Asbestos" is a generic term used for the fibrous form of a number of minerals. The mineral groups, mineral names, and chemical compositions are given below:

Group	Name	Chemical Formula
Serpentive	Chrysotile	$3MgO \cdot 2SiO_2 \cdot 2H_2O$
Amphibole	Anthophyllite	$(MgFe)_7Si_8O_{22}(OH)_2$
	Amosite	$(Fe)_7Si_8O_{22}(OH)_2$
	Crocidolite	$NaFe_8(SiO_3)_2 \cdot FeSiO_3 \cdot H_2O$
	Tremolite	$Ca_2Mg_5Si_8O_{22}(OH)_2$

Asbestos is fire resistant, flexible, and has very high tensile strength for its weight. Because of these attributes it has many industrial uses such as reinforced cement pipe and fireproof insulation. The chrysotile form has longer, more flexible fibers and is the most commonly used form.

There is substantial evidence that airborne asbestos is a carcinogen. Asbestos workers, as a group, suffer increased rates of cancer of the esophagus, stomach, colon, and peritoneum, as well as increased incidence of lung disease. The implication is that the inhaled asbestos is cleared from the lungs by mucous removal apparatus, then swallowed, and once in the gastro-intestinal tract, the asbestos fibers induce tumors (Kuschner, 1974).

In non-occupational exposure, however, the health effect of long term low level exposure is largely unknown.

The EPA is required by law to publish criteria for water quality for 65 pollutants with the protection of aquatic life and human health. The criterion for asbestos states: "For the maximum protection of human health from the potential carcinogenic effects due to exposure of asbestos through ingestion of contaminated water and contaminated aquatic organisms, the ambient water concentrations should be zero based on the non-threshold assumption for this chemical. However, zero level may not be attainable at the present time." (EPA, Ambient Water Quality Criteria, PB81-117335). Asbestos occurs naturally in many areas throughout the United States, and one would expect to find some asbestos in the water in those areas. In addition, about 200,000 miles of asbestos reinforced cement pipe are in service in the United States (Olson, 1974), much of it carrying drinking supply water. Finally, asbestos fibers have been used until recently in the manufacturing of filter material for the beverage industry. Even though asbestos is a carcinogen for which the EPA is obliged to recommend zero level water concentrations, its ubiquitous occurrence in the human environment will probably prevent that criteria from ever being achieved.

Common water treatment practices like sedimentation basins for effluents, and polelectrolyte coagulation followed by filtration for drinking water supplies can reduce asbestos concentrations substantially. The flocculation, sedimentation, and filtration process used at the Chicago Water Filtration Plants removed from seventy to ninety percent of the asbestos fibers present in the raw water of Lake Michigan (McMillan, 1977).

Asbestos in Limestone Effluents

Concentrations of chyrsotile asbestos found in the limestone mining process waters investigated varied from <0.07 million fibers per liter (mf/l) to 390 mf/l. In the cases where higher concentrations of asbestos were found, treatment of that water in sedimentation ponds substantially reduced the number of asbestos fibers (see Table 6-12). In areas where asbestos occurs in the bed rock or soil, asbestos concentrations in water can range from 0.7 to 4. mf/l (Kahle, 1980). Sedimentation basins can probably be used to achieve this level of asbestos in the effluents. Removal beyond this level may require more sophisticated techniques.

7.2 Ecological Effects of Limestone Quarry Effluents

Effluents from limestone quarry operations may cause significant impacts upon the turbidity, hardness, pH, sediment thickness and type, and both nutrient and toxicant levels in a receiving body of water (Figure 7-1). The effluents contain finely divided limestone, usually a mix of calcium and magnesium carbonates. The chemical constituents of limestone are non-toxic to humans and most forms of higher animal life and will be treated as such in this report. It is to be noted, however, that certain restricted habitats occur in streams or lakes which have a naturally low pH or are located in areas depleted in calcium or magnesium. In these areas, introduction of limestone quarry wastes could have a significant impact on the native biota. However, most, if not all, limestone quarries discharge into streams that arise adjacent to the quarry sites in soils already appreciably influenced by the surrounding limestone deposits. As such it is rare to find a quarry which discharges into a system that would be adversely affected by the chemical constituents of treated limestone effluents.

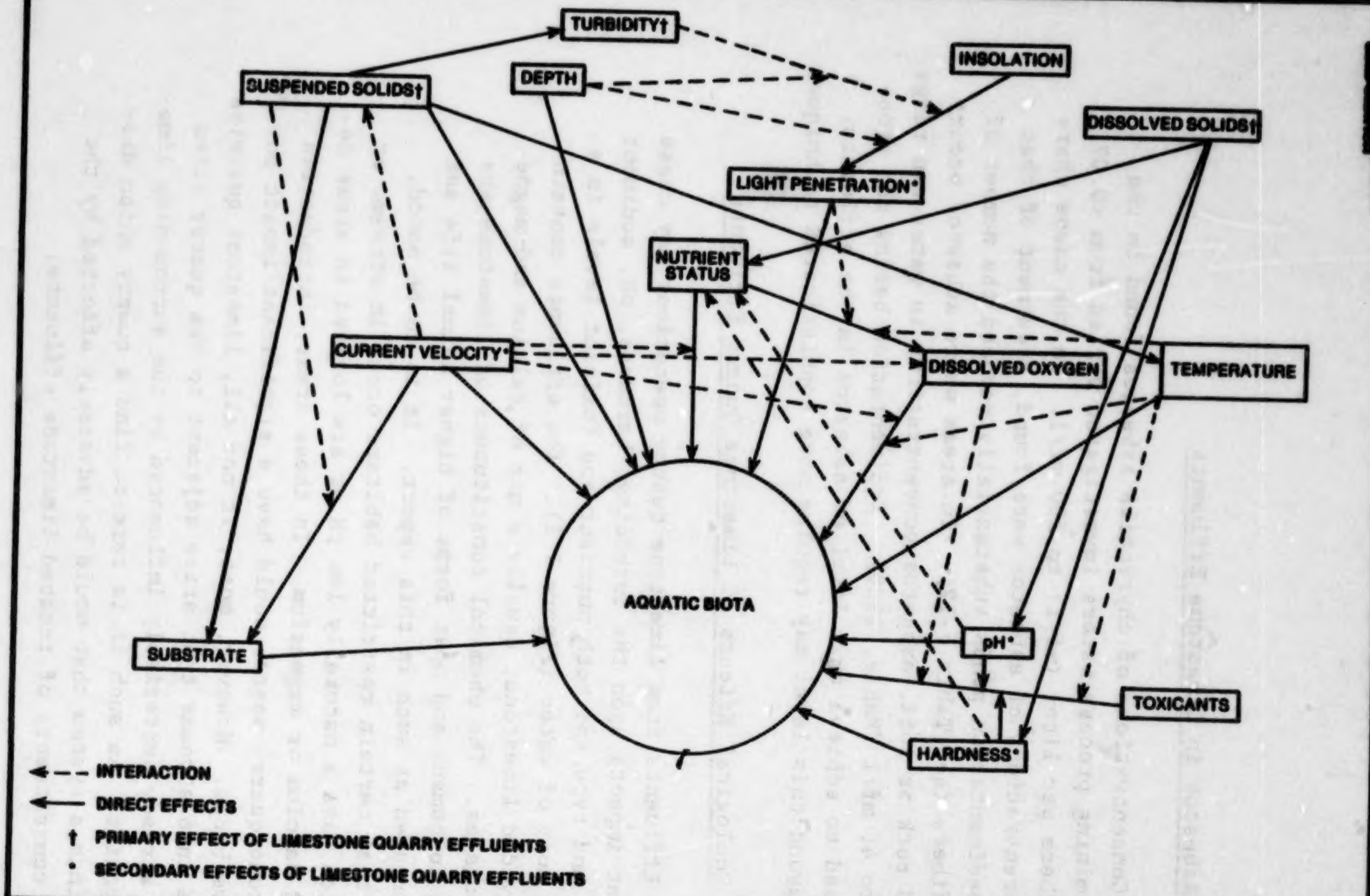
TURBIDITY†
INSOLATION
SUSPENDED SOLIDS†
DEPTH
DISSOLVED SOLIDS†
LIGHT PENETRATION*
NUTRIENT STATUS
CURRENT VELOCITY*
DISSOLVED OXYGEN
TEMPERATURE
AQUATIC BIOTA
SUBSTRATE
pH*
TOXICANTS
HARDNESS*
INTERACTION
DIRECT EFFECTS
† PRIMARY EFFECT OF LIMESTONE QUARRY EFFLUENTS
* SECONDARY EFFECTS OF LIMESTONE QUARRY EFFLUENTS

Figure 7-1. Effects of Limestone Quarry Effluents Upon Aquatic Communities

Limestone and limestone products such as lime can increase the pH of a receiving stream. This change in pH can free much of the phosphate found in bottom sediments causing an enrichment of the overlying waters, increased primary productivity, and a subsequent increase in fish yield. This effect has been used by fish farmers for centuries to increase yields. The same effect, however, can also free toxic substances in the sediments and make them available to the aquatic biota. It may also create a eutrophic condition because of the increased availability of plant nutrients. This may partially explain the synergistic effects noted by many researchers between some toxicants and turbidity.

Nitrate levels of a receiving stream may also be affected by limestone quarry operations. Ammonium nitrate is used as a high explosive in most quarries. Improper storage or incomplete combustion of the compound could result in increased levels of nitrates in surrounding streams. A similar situation has been found in coal mining in the Western United States in surface mining operations in semi-arid areas. In most areas the levels of ammonium nitrate from quarry operations are orders of magnitude less than the amount contributed by agricultural runoff. Using proper management practices, this should not be a concern in most limestone quarry operations.

The physical effects of the limestone quarry effluents on the resident biota of the receiving stream which are related to turbidity and sediment increases include:

- reduced primary productivity caused by decreased light penetration;
- siltation of spawning beds, redds, and nests of fish causing reproductive failures;

- reduction in viability of fish eggs caused by reduced oxygen availability;
- restricted visibility which place those aquatic predators which depend on visual cues at a disadvantage vis a vis those predators which depend upon other cues;
- decrease in the number of available suitable benthic invertebrate habitats;
- pathological changes in gill structure in both fish and invertebrates (fusion of lamellae and thickening of respiratory epithelium);
- reduced capability to regulate ionic balance in fishes because of reduced capacity of the gills;
- increase in disease susceptibility in affected biota;
- reduction in feeding rate in filter feeders correlated with an increase in the amount of energy expended by those feeders per unit food; and
- species shifts in the benthic invertebrates and attached algae (both macrophytic and periphytic) to more sediment tolerant forms.

These effects are extrapolated from the literature pertaining to the effect of suspended solids and turbidity and applied to limestone quarries. We attempted on a small scale to verify these effects with sampling and analyses.

Most limestone quarries which discharge effluents are located in the eastern United States near metropolitan centers which serve as the market for their product. Receiving streams in these areas are already impacted by a mixture of agricultural, sanitary, industrial, and urban wastes and the effects of the limestone effluents are overshadowed by the impacts of these pre-existing stresses.

In a few of the cases examined in this study best management practices could appreciably lower the suspended sediment load to the receiving stream. For example, proper conveyance of waste streams and proper design of outfall pipes could cut sediment loads. Non-point source sediment washed from the stock piles and yard should be controlled to reduce the sediment load of adjacent creeks. Diesel fuel and oil wastes from trucks and heavy equipment can contribute to the effluents from a quarry site and should be minimized.

7.2.1 Effects of Limestone Quarry Effluents on Fish

Limestone and limestone products are non-toxic to those fish adapted to life in hard, alkaline waters. The main effects of limestone quarry effluents on fish in most streams in the eastern United States are caused by the increase in suspended sediments and turbidity caused by the effluent. The National Academy of Sciences (1973), expanding on an idea proposed by Tarzewell (1957), states that the "...effect of color and turbidity should not change the compensation point* more than 10 percent from its seasonally established norm, nor should such a change place more than 10 percent of the biomass of photosynthetic organisms below the compensation point..." They also suggest that aquatic communities should be protected if the maximum (maximum in this case refers to the naturally occurring maximum in the receiving body of water) concentrations of suspended solids are exceeded by artificial additions (Table 7-9).

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*The compensation point is the depth at which the light level exists needed to balance primary productivity (photosynthesis) with respiration.

TABLE 7-9. LEVELS OF PROTECTION VERSUS NATURAL SUSPENDED SEDIMENT LOADS (After NAS, 1973)

Level of Protection Proposed	Natural Suspended Solids Maximum Concentration
High level of protection	25 mg/liter
Moderate level of protection	80 mg/liter
Low level of protection	400 mg/liter
Very low level of protection	>400 mg/liter

Most streams in the study areas are exposed at present to periods during high flow events when suspended solids exceed 400 mg/liter. As was proposed, the EPA criteria for suspended solids and turbidity were established at a level that "...should not reduce the depth of the compensation point for photosynthetic activity by more than 10% from the seasonally established norm for aquatic life." The EPA criteria are essentially those of the NAS report with the major exception of the recommendation to rank the sensitivity of the receiving water in accordance with naturally occurring variation in suspended sediments and turbidity.

EIFAC (1965) found that for inert suspended solids in European waters there is no evidence that concentration of suspended solids less than 25 ppm have any harmful effects on fisheries. They also found that it should be possible to maintain good or moderate fisheries in waters which normally contain 25 to 80 ppm suspended solids (criterion b). Other factors being equal, however, the yield of fish from such waters might be somewhat lower than from those in criterion (a) (<25 ppm). In addition, waters normally containing from 80-400 ppm suspended solids (criterion c) are unlikely to support good freshwater fisheries, although fisheries may sometimes be found at the lower concentrations within this range. Finally, EIFAC (1965) indicates that at the best, only poor fisheries are likely to be found in waters which normally contain more than 400 ppm suspended solids (criterion d). Gammon (1970) states "Thus criterion (b), while it may apply to the biota of continental Europe, may be too liberal for populations in the U.S. Certainly at the ranges from about 50 to 80 ppm or mg/ℓ it appears that significant biotic reductions will definitely occur."

Suspended sediments affect adults, eggs, alevins, and fingerlings. The mode of action and levels of concern may vary from life stage to life stage. The TSS levels currently discharged by the limestone quarries in this study are at levels which pose little threat to the existing ecology of the studied receiving streams.

7.2.1.1 Effects on Adult Fish

Wallen (1951) in testing 380 fish (16 species) observed behavioral changes at turbidities greater than 20,000 ppm and noted that these effects could be offset somewhat by aeration and movement of the fish. Apparently death in cases of turbidity induced lethality is caused by anoxia and CO_2 retention caused by clogging of the gills (Ellis, 1937). Ellis (1944) states that suspended sediments may cause abrasions on the gills allowing disease organisms and parasites to infect the fish. Herbert and Merkens (1961) indicate that the suspended sediments cause fusion of adjacent gill lamellae and a thickening of respiratory epithelium in affected fish. Cairns (1968) adds that turbidities may interfere with gill mediated ammonia and urea excretion as well as oxygen uptake. The oxygen data is based on experimental evidence of Smith et al (1965), who noted, using wood particles as the suspended sediment, that oxygen uptake suppression varied as the type of wood used in the experiments varied. Nonetheless, the movement of the gills and their condition is critical in maintaining gill capillary circulation (Cairns, 1968).

Cordone and Kelley (1961) found that in fish exposed to turbid water and toxic chemicals (copper and zinc), death occurred more rapidly than in the group exposed to toxic water alone. They postulate that the effect of the suspended sediments on gill action was exacerbated by the presence of toxic chemicals.

In an attempt to define harmful levels of suspended sediments, Herbert and Merkens (1961) exposed fish to kaolin or diatomaceous earth suspensions. No difference was noted in the response of the fish to these suspensions. In an experiment measuring long term survivability, they found that 30 ppm caused no observable effects, 90 ppm caused slight effects, while 270 ppm caused deaths. No difference in growth was found between the controls and experimental fish, which conflicts in some degree with the field data outlined below.

Of the common game species in Table 7-10, only Pomoxis annularis (white crappie) is tolerant to high turbidities. They in fact enjoy a competitive advantage in turbid waters.

Salmonids as a group exhibit avoidance of turbid waters when possible. Smith (1940) observed that King Salmon avoided a section of muddy water in the Yuba River in favor of the clear tributaries. Although Benoit et al (1968) found that young salmon could tolerate exposure to high concentrations of sediment for up to 120 hours, Bachmann (1958) found that cutthroat trout did not feed at suspended sediment concentrations at a maximum of

TABLE 7-10. THE EFFECTS OF SUSPENDED SEDIMENTS ON ADULT FISH OF COMMON GAME SPECIES

Species	Effect	Reference
Lepomis cyanellus (green sunfish)	● slow growth rate in turbid waters	Hastings and Cross, 1962
	● turbidity (14-16 JTU's) did not affect feeding or attack behavior but did affect the social hierarchy and increased scraping behavior	Heimstraw et al., 1969
Lepomis gulosus (warmouth)	● growth slower in turbid waters	Hubbell, 1966
Lepomis microlophus (redeared sunfish)	● requires relatively clear water	Buck, 1956
	● growth slower in turbid ponds	
Lepomis macrochirus (bluegill)	● growth slower in turbid ponds	Hastings and Cross, 1962 Shireman, 1968 Buck, 1956
Lepomis megalotis (longear sunfish)	● intolerant of large amounts of silt	Raney, 1965
Micropteris salmoides (largemouth bass)	● low K (condition index) associated with turbidity	Morgan, 1958
	● 14-16 JTU turbidity decreased activity and bass demonstrated "coughing"	Heimstra et al., 1969
Pomoxis annularis (white crappie)	● very tolerant of turbidity and siltation	Walberg, 1964
	● does not compete well with bluegills, black crappies or largemouth bass in clear waters	Trautman, 1957

35 ppm, although they exhibited no outward signs of distress. Campbell (1954) exposed rainbow trout fingerlings to 1,000-2,000 ppm for twenty days. In the control condition 9.5 percent of the fingerlings died, while in the experimental condition 57 percent died. Griffin (1938), working with cutthroat trout and king salmon, found that both species survived and fed for thirty days in water that averaged 360 to 600 ppm and peaked at 3,500 ppm. Herbert and Richards (1963) investigated the status of brown trout in a clear control river, a river that averaged 60 ppm suspended clay solids and had stretches with 1,000 - 6,000 ppm. In that section of river with 60 ppm suspended solids, there was no detectable difference from the control river. In the section with 1,000 - 6,000 ppm the trout population was one-seventh of the control.

Wallen (1951) also determined the average fatal turbidities for sixteen species of fish. These values ranged from 38,250 ppm for Ambloplites rupestris to 222,000 ppm for Ameiurus melas (black bullhead).

From the above review it can be seen that adult fish can temporarily withstand high levels of suspended sediment in their environment. Mortality in the case of adult fish killed by high sediment concentrations is due to gill clogging and abrasion. Behavioural changes occur before lethal levels of suspended solids are reached. Salmonids are more sensitive than most other adult fish to suspended solids.

Adult fish in a natural situation are able to avoid the effects of turbidity by migrating to a non-impacted area or by seeking shelter in a non-turbid refugia. The more damaging aspects to the fish population in bodies of water with high levels of turbidity are the reduction of food organisms (invertebrates, algae, and plankton), and reduction in available nesting sites either from siltation of gravel beds or through a reduction in macrophytic vegetation.

7.2.1.2 Effects on Fish Reproduction Behavior and Success

Limestone quarry effluents may adversely affect the reproductive behavior of adults, viability of fish eggs, and the survival of juvenile fish.

Sediments affect the reproductive behavior, eggs, and juveniles of different species in different ways. For example Gammon (1970) found that longear sunfish (Lepomis megalotis) preferentially nested in a clear tributary of Deer Creek, rather than in Deer Creek itself and inferred that nesting sites in Deer Creek were abandoned as turbidity increased. Wolf (1950) cites erosion of topsoil and increased turbidity as the main reason for the disappearance of the Atlantic salmon from its previous range in the Eastern United States.

Eggs are affected by the blanketing action of the sediments produced by quarries. This blanketing action causes a lowering of oxygen levels and a buildup of CO_2 levels near the eggs. Harrison (1923), working with eyed eggs of sockeye salmon (Table 7-11), found an increase in mortality in those eggs exposed to sediments. Schubel et al (1974) demonstrated that sediment additions of up to 500 mg/liter had no effect on the eggs of yellow perch or striped bass, but that 1,000 mg/liter lowered hatching success. Hobbs (1937), working on king salmon, brown, and rainbow trouts correlated egg mortality with sediment load. Most losses occurred before the eyeing stage was reached. Cordone and Kelley (1961), after reviewing the available literature, reached the conclusion that "...the effect of sediment upon alevins and especially eggs of salmonids can be and probably often is disastrous. Even moderate deposition is detrimental."

Sediments can also adversely affect nesting site availability and nesting habits in certain species. Bluegills (Lepomis macrochirus) and pumpkinseeds (Lepomis gibbosus)

TABLE 7-11. SUMMARY OF HARRISON'S (1923) DATA ON MORTALITY OF SOCKEYE SALMON EGGS UNDER VARIOUS SEDIMENT LOADS

Number of Eggs Planted	Description of Nest	Number of Eggs Hatched
500	Gravel from size of pea to hickory nut, some clean sand	350
500	Gravel as above with a ½" coating of silt	325
500	Fine gravel sand, and small amount of clay in sand	200
500	Fine gravel and much clay or mud in sand	170
500	Gravel from size of hickory nut to walnut, very little sand, no clay or top covering of silt	420

prefer clean sand for nesting while the warmouth (Lepomis gulosus) prefers to nest in the shelter of a stump or rooted aquatic vegetation (Larimore, 1957). The dearth of rooted aquatic vegetation in sediment loaded streams also may lower fry survival rates by removing refuges. Male longear sunfish (Lepomis megalotis) build nests in clean gravel (Huck and Gunning, 1967). Spotted bass (Micropterus punctulatus) prefer mud bottoms or gravel bottoms for nesting sites (Howland, 1931). Smallmouth bass (Micropterus dolomieu) prefer coarse rubble as a nesting site substrate. Occasionally smallmouths will nest on soft sediments after covering them with woody debris and clam shells (Turner and MacCrimmon, 1970). Smallmouth nests are usually located in areas of low current velocity (Surber, 1943). Largemouth bass (Micropteris salmoides) will not nest on silt bottoms (Robinson, 1961), preferring building nests on sand, gravel, roots, or aquatic vegetation (Mraz et al., 1961). Often largemouth nests are located near boulders or pilings (Hunsaker and Crawford, 1964). White crappie (Pomoxis annularis), however, often spawn in highly turbid water under tree roots or similar sheltered areas (Morgan, 1954).

From the above review, it can be stated that sediments can interfere with the reproductive success of most common freshwater game fish, salmonids being the most sensitive. The centrarchid population is generally affected by a lack of suitable nesting places. The effects on both eggs and reproductive bahavior are species specific and a continued input of non-lethal amounts of sediment into a receiving body of water could cause shifts in species abundance and community structure.

7.2.2 The Effects of Limestone Quarry Effluents on Benthic Communities

The component of limestone quarry effluents most responsible for changes in the benthic community is sediment. This stonedust can modify habitats, smother sensitive organisms, and indirectly damage the benthic community by reducing available light to benthic plants and by increasing the migration rate of benthic invertebrates.

Benthic Invertebrates

Gammon (1970) reported on a four year study of the effects of limestone quarry effluents upon stream biota and concluded that light sediment inputs (less than 40 mg/liter) caused a 25 percent reduction in macroinvertebrate density. Heavier sediment loads (greater than 120 mg/liter) resulted in a 60% reduction in macroinvertebrate population density. Gammon also reported that most invertebrates responded to the sediment load in a like degree and thus the diversity of the system was not affected. This second conclusion has been contradicted in the literature from studies done in other locales (Chutter, 1969). Sediment introductions in Gammon's study also increased the drift rate of benthic invertebrates. As a summary, Gammon states that "reduction in the standing crops of fish and macroinvertebrates were detected in a short segment of stream which received a load of suspended inorganic solids of no more than, and during the spring and winter less than, 40 mg/l more than the normal concentration during a part of each day. Suspended material as well as settled sediment was responsible..."

Ellis (1931), commenting on the Mississippi, Tennessee, and Ohio Rivers stated that freshwater mussel populations were being decimated by smothering of the less resistant young mussels and by a drawdown in the oxygen content of bottom waters due to a covering of organic wastes by sediments and the creation of anoxic conditions. A combination of silting followed by flooding reduced the bottom fauna to 7.3 organisms/ft^2 as composed to 25.5 organisms/ft^2 in an unaffected area.

The distance downstream that effects could be detected vary from report to report (Table 7-12).

The effects of inorganic sediments on benthic invertebrates varies according to the type of organism and its habitat. The type of bottom (rubble, gravel, sand, or mud) is of paramount importance in determining the productivity of a stream. Rubble bottoms allow the highest production and inorganic silt and mud bottoms are the least productive. The lowest productivities are found on bedrock or fine sand (Smith and Moyle, 1944). This bottom effect has been noted many times in the literature. Cordone and Kelley (1961) summarize: "The fact that insects are less abundant on sand bottoms than on gravel and less abundant on gravel than on rubble, has been adequately reported. The processes of erosion greatly increase the relative proportion of finer materials in stream bottom, and of course the deposition of mining debris or gravel plant waste accomplishes the same thing in a more startling and accelerated fashion. To us, there would appear to be adequate evidence that increasing the amount of fine material in the bottom of streams will eventually result in a declining bottom fauna."

7.2.3 Plankton, Periphyton, Macrophytes and Attached Algae

Zooplankton can be directly affected by sediments at concentrations of 300-500 ppm due to clogging and overloading of their filter-feeding apparatus and digestive organs (Stephan, 1953). Robertson (1957) determined that different suspended

TABLE 7-12. DISTANCE DOWNSTREAM SEDIMENT INDUCED EFFECTS COULD BE OBSERVED

Location	Type of Operation	Effects	Author
Wynooche River, Washington	Gravel Washing	75% reduction in benthic invertebrates at 200 yards to 0.3 miles downstream. 85% reduction 1.7 miles downstream.	Ziebell and Knox, 1957
Chehalis River, Washington	Gravel Washing	90% reduction in bottom organisms 100 yards below outfall. 34% reduction 4 miles downstream. Normal 6 1/2 miles downstream.	Ziebell, 1957
Powder River, Oregon	Gold Dredge	Almost complete absence of organisms for 15-20 miles downstream. (However, 1 year after silt was flushed from the river, the organisms returned in abundance.)	Wilson, 1957
Seigel Creek, Idaho	Dredge	1/4 mile downstream devoid of organisms. At one mile there was a 50% reduction.	Casey, 1959
Cold Creek, Trickee River, California	Gravel Washing	Greater than 90% reduction at outfall. 75% reduction 10 miles downstream	Cordone and Pennoyer, 1960
Trout Stream, Cotes du Nord, France	Sand Washing	Bottom fauna disappeared to 4 kilometers downstream, where the suspended sediment load fell to 29 ppm.	Vivier (in EIFAC, 1965)

solids caused differing toxicities in Daphnia magna, and that at low levels, inorganic sediments may increase the organism's productive rate.

Phytoplankton growth can be reduced by the shading effect of suspended sediments. King and Ball (1964) found a 61 percent reduction in primary production in a stream impacted by sediments from highway construction. This reduction in primary production is followed by a reduction in secondary production. A decrease in the amount of phytoplankton available in an aquatic ecosystem will be reflected in a decrease in the number of organisms dependent upon that phytoplankton as a food source.

Burris and Cooper (1977) compared turbidity and growth of the diatom Melosira sp. in Grenada, Mississippi. This study indicates that in the range of 15-90 ppm SiO_2 turbidity, Melosira can grow well. Melosira reached a level of 300,000 cells/liter while the water column had a turbidity of 52 ppm SiO_2. The authors state that turbidity stimulated the growth of plankton. However, no causal relationship can be demonstrated based on their data. Variations in temperature, nutrient levels, and season were unaccounted for in the study. The conclusion that can be drawn from the data is that Melosira can maintain a healthy population while subjected to levels of turbidity less than 90 ppm SiO_2.

Westlake (1966) states that in turbid waters the subsurface light at one meter depth can be reduced by a factor of 10^{-6} compared to surface levels.

The distribution of periphyton and attached algae are affected both by the blanketing effects of sediment and by lack of suitable substrates. Many species of diatoms and green algae require a solid surface on which to attach. When there is no solid surface, these attached algae and periphyton cannot exist.

The response of aquatic macrophytes to limestone quarry effluents is somewhat more complex than that of plankton, periphyton, or benthic invertebrates. In addition to the physical effect or blanketing action of the sediments, there is a physiological interaction. Some aquatic angiosperms are capable of using the biocarbonate ion, HCO_3^-. These plants can use the carbon of the biocarbonate ion for photosynthetic carbon fixation as well as the carbon of the CO_2 molecule, as in normal photosynthesis. Since in most natural water the HCO_3^- ion has a greater abundance than CO_2, HCO_3^- use during photosynthesis confers a competitive advantage to the plant that uses it. Hard water lakes of elevated pH and alkalinity offer these HCO_3^- utilizing plants a highly productive habitat. Hutchinson (1975) summarized Moyle's (1945) classification of aquatic North American angiosperms according to their tolerances for alkalinity (Table 7-13). Another group of photosynthetic organisms characteristic of hard waters are the Charophytes, *Chara* and *Nitella*. Of the two, *Chara* is more characteristic of hard water. Limestone quarries have a characteristic aquatic flora dominated by masses of *Chara*.

Aquatic plants also vary in their resistance to deposited sediments. Some, such as *Isoetes* sp., are intolerant of sediment deposition and unable to grow in areas of rapid sedimentation. Hutchinson (1975) uses the example of a small English lake with *Juncus bulbosus* f. fluitans in areas of most rapid sedeimentation, *Nitella opaca* in areas of less deposition, and *Isoetes lacustris* in areas where the deposition was slight.

TABLE 7-13. RANGE OF ALKALINITY, pH, SULFATE, AND TOTAL SALINITY FOR SOME NORTH AMERICAN WATER PLANTS

Plant Groupings by Habitat Type	Species	Alkalinity as HCO_3^- (mg liter^{-1})	pH	CO_2 (mg liter^{-1})	Salinity[d] (mg liter^{-1})
I. Low Dissolved Solids Group: alkalinity <60 mg HCO_3^- liter^{-1}, lowest pH $\leq$7.0, sulfate $\leq$10.0 liter^{-1}, Moyle's soft-water subgroup 1.					
	Isoetes braunii	10-55	7.0-8.0	0.0-4.5	
	Sparganium fluctuans	24-55	7.0-7.3	0.5-6.0	
	Potamogeton spirillus	22-56	7.0-8.3	0.0-3.0	
	Scirpus subterminalis	10-52	6.8-7.5	n.d.	
	Eriocaulon septangulare	12-54	6.7-7.8	0.0-5.8	
	Lobelia dortmanna	15-51	6.8-7.5	0.9-10.2	
	Nuphar microphylla	9-50	6.8-7.3	0.5-6.0	
	N. rubrodisca	0.6-39	6.8-7.3	0.5-1.0	
	I. macrospora[a]				
	Sparganium augustifollium[a]				
	S. minimum[a]				
	Najas gracillima[a]				
	Nymphaea tetragona[a]				
	Ranunculus trichophyllus var. *eradicatus*[a]				
	Callitriche hermaphroditica[a]				
	Elatine minima[a]				
	Myriophyllum alterniflorum[a]				
	M. farwellii[a]				
	M. tenellum[a]				
	Littorella americana[a]				

(Continued)

TABLE 7-13. RANGE OF ALKALINITY, pH, SULFATE, AND TOTAL SALINITY FOR SOME NORTH AMERICAN WATER PLANTS (Continued)

Plant Groupings by Habitat Type	Species	Alkalinity as HCO_3^- (mg liter^{-1})	pH	CO_2 (mg liter^{-1})	Salinity[d] (mg liter^{-1})
II. Euytropic Intermediate Group: ranging from dilute (<15 mg HCO_3^- liter^{-1}) to fairly hard (<100 mg HCO_3^- liter $^{-1}$) water; Moyle's soft-water subgroup 2, with some changes.					
• Lowest alkalinity <1 mg HCO_3^- liter $^{-1}$; sulfate variable, often high					
	Potamogeton gramineus	0.6-186	7.0-8.5	0.0-17	
	Sagittaria latifolia	0.6-363	6.3-8.8	0.0-199	
	Eleocharis palustris	0.6-273	6.3-9.0	0.0-396	
	E. palustris var. *major*	0.6-223	6.8-8.8	0.0-155	
	Phragmites australis	0.6-363	6.3-9.0	0.5-396	
• Lowest alkalinity 9-15 mg HCO_3^- liter^{-1}; sulfate usually low					
	Equisetum fluviatile	9-363	6.8-8.8	0.0-16	
	Potamogeton alpinus	15-141	7.0-8.6	0.5-4	
	P. etihydrus	12-148	6.7-8.6	0.6-6	
	P. praelongus	13-375	7.1-9.0	0.0-143	
	Glyceria borealis	10-229	6.8-8.8	0.5-17	
	Calla palustris[a]				
	Potentilla palustris[a]				
	Callitriche palustris[a]				
	Myriophyllus verticillatum[a]				
	P. obtusifolius[a]				
	Glyceria neogaea[a]				
III. Hard-water Group: alkalinity always >15 mg HCO^- liter^{-1}.					
• Lowest alkalinity 15-30 mg HCO_3^- liter^{-1}; sulfate <75 mg liter^{-1}					
	Pontederia cordata	22-113	7.2-7.9	0-10	
	Potamogeton amplifolius	15-255	7.1-8.8	0-28	
	P. natans	23-376	6.8-9.0	0-50	
	Sagittaria cristata	23-223	7.2-8.8	4-24	

(Continued)

TABLE 7-13. RANGE OF ALKALINITY, pH, SULFATE, AND TOTAL SALINITY FOR SOME NORTH AMERICAN WATER PLANTS (Continued)

Plant Groupings by Habitat Type	Species	Alkalinity as HCO_3^- (mg liter^{-1})	pH	CO_2 (mg liter^{-1})	Salinity^d (mg liter^{-1})
• Lowest alkalinity 15-30 mg HCO_3^- liter^{-1}; sulfate <600 mg liter^{-1}					
	Heteranthera dubia	28-299	7.6-9.0	0-318	
	Ceratophyllum demersum	28-458	6.3-9.0	0-332	
	Myriophyllum exalbescens	28-458	7.2-8.9	0-317	350-1465
	Utricularia vulgaris var. americana	20-363	6.8-8.9	0-318	458-1089
	Elodea nuttallii	27-247	7.3-8.8	0-282	
	Nymphaea tuberosa	23-363	6.3-9.0	0-178	
	Nuphar variegata	9-268	6.8-8.6	0-178	
	Potamogeton zosteriformis	22-299	6.9-9.0	0-282	501
	Najas flexilis	23-375	7.2-9.0	0-318	
	Sagittaria cuneata	24-458	7.3-9.0	0-317	
	Vallisneria americana	23-338	7.0-8.9	0-318	
	Eleocaris acicularis	23-458	7.0-8.9	0-318	
	Acorus calamus	24-247	7.3-8.8	4-318	
• As above but sulfate can be very high					
	Typha latifolia	12-458	6.3-9.0	0-1296	
	Scirpus acutus	21-273	7.2-9.1	0-1296	
• Lowest alkalinity, between 30 and 150 mg HCO_3^- liter^{-1}; sulfate <75 mg liter^{-1}					
	Potamogeton friesii	87-458	7.7-8.8	1-62	
	P. gramineus f. myriophyllum	37-207	7.0-8.8	0-39	
	P. ilinoensis	40-200	7.7-8.8	0-18	
	P. robbinsii	40-176	7.2-8.4	0-18	
	P. berchtoldii sub puscillus	38-228	7.0-8.8	0-17	

(Continued)

TABLE 7-13. RANGE OF ALKALINITY, pH, SULFATE, AND TOTAL SALINITY FOR SOME NORTH AMERICAN WATER PLANTS (Continued)

Plant Groupings by Habitat Type	Species	Alkalinity as HCO_3^- (mg liter^{-1})	pH	CO_2 (mg liter^{-1})	Salinity[d] (mg liter^{-1})
	P. strictifolius[b]	39-321	7.4-9.0	1-62	
	Sagittaria rigida	40-363	7.4-8.8	0-62	
	Elodea canadensis	43-363	7.0-8.8	0-37	501
• Lowest alkalinity >30 mg HCO_3^- liter^{-1}; sulfate <600 mg per liter^{-1}					
	Sparganium euycarpum	43-460	7.2-8.8	2-199	
	Potamogeton foliosus	45-279	7.2-8.8	0-282	458-1431
	P. nodosus	49-380	7.3-8.8	5-199	
	P. richardsonii	38-451	7.0-9.1	0-318	
	Najas guadalupensis	92-195	7.2-8.6	36-177	
	Alisma triviale	39-364	7.3-8.5	5-199	
	Leerisa oryzoides	37-338	7.2-9.0	0-178	
	Zizania aquatica	46-364	7.2-8.6	3-282	
	Scirpus heterochaetus	50-243	7.3-8.6	12-282	
	Lemna minor	50-320	6.3-9.0	0-254	
	Lemna trisulca	50-363	7.2-8.8	0-332	
	Wolffia columbiana	104-268	7.2-8.4	20-178	
	Polygonum coccineum	91-253	7.7-8.8	16-178	
	P. natans	37-317	7.7-8.8	3-282	
	Hippuris vulgaris	37-362	6.8-8.8	0.5-199	
• As above but sulfate can be very high					
	Potamogeton pectinatus	39-458	6.3-9.0	0.5-1297	350-35,873
	Zannichelia palustria var. *major*	92-412	7.6-9.0	8-1297	458-1465
	Scirpus fluviatilis	37-268	7.0-9.1	0.5-630	
	S. americanus	107-338	7.4-8.9	3-1296	
	Spirodela polyrhiza	60-363	6.3-8.8	1-619	

(Continued)

TABLE 7-13. RANGE OF ALKALINITY, pH, SULFATE, AND TOTAL SALINITY FOR SOME NORTH AMERICAN WATER PLANTS (Continued)

Plant Groupings by Habitat Type	Species	Alkalinity as HCO_3^- (mg liter^{-1})	pH	CO_2 (mg liter^{-1})	Salinity[d] (mg liter^{-1})
IV. Alkali Water Group: in water with at least 150 mg HCO_3^- liter^{-1} and 50 mg sulfate liter^{-1}, tolerances usually much higher, Moyle's alkali water group					
	Ruppia maritima	179-458[c]	8.1-9.0	50-396	457-77,386
	Najas marina	179-458	8.2-9.0	50-1297	624-1089
	Scirpus paludosus	179-241	8.4-9.0	254-395	

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[a] Species for which there are inadequate data, but most likely are in Group I.

[b] Including var rutiolides as well as typical var. strictifolius.

[c] Moyle's records sub R. occidentalis, which is usually not regarded as distinct from R. maritima.

[d] Salinity ranges from Metcalf, 1931.

Source: Moyle, 1945; personal observation.

In summary, aquatic macrophytes can be greatly effected by both sediment deposition from limestone quarry effluents and by the alkalinity and high pH associated with those effluents. As was stated earlier, however, since most limestone quarries are located in areas of the United States in which there are extensive limestone deposits, it is expected that the vegetation present would already be adapted to that type of environment.

8.0 TREATMENT TECHNOLOGIES

8.1 Description of Treatment Technologies

Treatment of limestone quarry wastewaters consists mainly of suspended solids removal. Major technologies employed include settling ponds, flocculation followed by settling, clarifiers, screens and filters. Of these, settling ponds are by far the most used with 95-97% of treatment facilities using this method. Flocculation and clarifiers are employed at 2-5% of existing facilities and screens and filters are rarely required (EPA, 1976).

8.1.1 Settling Ponds

The versatility, ease of construction and relatively low cost, explains the wide application of settling ponds compared to other technologies. The performance of these ponds depends primarily on the settling characteristics of the suspended solids, the flow rate through the pond and the pond size. Settling ponds can be used over a wide range of suspended solids levels. Often a series of ponds is used, with the first collecting the heavy load of easily settled material and the others providing additional solids removal to achieve the desired suspended solids level. As the ponds fill with solids they can be dredged to remove these solids or they may be left filled and new ponds provided. The choice often depends on whether land for additional new ponds is available. When suspended solids levels are low and ponds large, settled solids build up so slowly that neither dredging nor pond abandonment is necessary for a period of many years.

In many cases, settling is a preliminary step in the recycle of water for washing purposes. The level of suspended solids commonly viewed as acceptable in recycled water used for construction materials washing is 200 mg/ℓ and higher. The TSS levels obtained after settling in ponds are adequate for recycling purposes.

8.1.2 Flocculation

Flocculating agents increase the efficiency of settling facilities. They are of two general types: ionic and polymeric. The ionic types such as alum, ferrous sulfate and ferric chloride function by neutralizing the repelling double layer ionic charges around the suspended particles, thereby allowing the particles to attract each other and agglomerate. Polymeric types function by physically trapping the particles.

Flocculation agents can be used with minor modifications and additions to existing treatment systems; but the costs for the flocculating chemicals are often significant. Ionic types are used in 10 to 100 mg/ℓ concentrations in the waste water while the higher priced polymeric types are effective in the 2 to 20 mg/ℓ concentrations.

8.1.3 Clarifiers

Clarifiers, screens and filters are used in less than 1% of the treatment facilities of the mineral mining industry (EPA, 1976). Clarifiers are essentially tanks with internal baffles, compartments, sweeps and other directing and segregating mechanisms to provide efficient concentration and removal of suspended solids in one effluent stream and clarified liquid in the other. Screens are restricted to removing the larger

(50-100 micron) particle size suspended solids which often can be sold as useful product.

8.1.4 Filtration

Filtration is accomplished by passing the waste water stream through solids-retaining particulates such as sand, gravel, coal or diatomaceous earth using gravity, pressure or vacuum as the driving force. Filtration is versatile in that it can be used to remove a wide range of suspended particle sizes. The large volumes of many waste water streams found in minerals mining operations require large filters. The cost of these units and their relative complexity, compared to settling ponds, has restricted their use to a few industry segments committed to complex waste water treatment.

8.1.5 Water Management Practices

Operational practices at several of the quarries visited negated the beneficial effects of the treatment processes. The practice of discharging treated effluent across an unpaved road that is heavily travelled by trucks causes a resuspension of particles (Figure 5-14). A culvert under the road to transport the treated effluent to the receiving stream would prevent the recontamination of the discharge.

Another practice that causes resuspension of solids is that of allowing the treated discharge to "fall" several feet from the outfall structure into the stream bed (Figure 5-4). This practice agitates bottom sediments in the vicinity of the outfall. Proper design of the outfall structure would prevent this resuspension of particles.

In addition, other actions that would reduce impacts from limestone quarrying on receiving streams include storing and using ammonia nitrate in a manner that minimizes nitrate contamination of streams, and isolating oil storage and oil wastes from the quarry waste effluent stream.

8.2 Treatment Cost

The effluent control costs for the crushed stone industry are associated with the treatment and storage of suspended solids. Current treatment practices consist of either direct discharge, sedimentation ponds or sediment ponds with recycle. The required ancillary equipment primarily consists of the water handling system (e.g. pump, pipe, etc.). In some specific cases a flocculating agent might be necessary to enhance the settling rate of the suspended solids.

An estimate of costs for a prototype crushed stone facility was made in 1976 for the EPA Effluent Guidelines Development Document. This analysis was updated and expanded in the EPA document "Economic Analysis of Effluent Guidelines, Mineral Mining and Processing Industry".

Cost information contained in the Development Document was assembled directly from industry, waste treatment and disposal contractors, engineering firms, equipment suppliers, government sources, and published literature. Whenever possible, costs were taken from actual installations, engineering estimates for projected facilities as supplied by contributing companies, or from waste treatment and disposal contractors quoted prices.

Capital investment estimates for this study were based on 10 percent cost of capital, representing a composite number for interest paid or return on investment required. All cost estimates were based on August 1972 prices.

The useful service life of treatment and disposal equipment can vary depending on the nature of the equipment and process involved, its usage pattern, maintenance care and numerous other factors. Individual companies may apply service lives based on their actual experience for internal amortization. The Internal Revenue Service provides guidelines for tax purposes which are intended to approximate average experience. Based on discussions with industry and condensed IRS guideline information, the following useful service life values were used:

1)	General process equipment	10 years
2)	Ponds, lined and unlined	20 years
3)	Trucks, bulldozers, loaders and other such materials handling and transporting equipment.	5 years

The economic value of treatment and disposal equipment and facilities decreases over its service life. At the end of the useful life, it is usually assumed that the salvage or recovery value becomes zero. For IRS tax purposes or internal depreciation provisions, straight line, or accelerated write-off schedules may be used. Straight line depreciation was used solely in the Development Document.

Capital costs were defined as all front-end out-of-pocket expenditures for providing treatment/disposal facilities. These costs included costs for research and development necessary to establish the process, land costs when applicable, equipment, construction and installation, buildings, services, engineering, special start-up costs and contractor profits and contingencies. Most if not all of the capital costs are accrued during the year or two prior to actual use of the facility. This present worth sum was converted to equivalent uniform annual disbursements by utilizing the Capital Recovery Factor Method:

$$\text{Uniform Annual Disbursement} = \frac{P(i)(1+i)^n}{(1+i)^n - 1}$$

Where P = present value (capital expenditure),
i = interest rate, %/100,
n = useful life in years

Land-destined solid wastes require removal of land from other economic use. The amount of land so tied up will depend on the treatment/disposal method employed and the amount of wastes involved. Although land is non-depreciable according to IRS regulations, there are numerous instances where the market value of the land for land-destined wastes has been significantly reduced permanently, or actually became unsuitable for future use due to the nature of the stored waste. The general criteria applied to costing land are as follows:

1) If land requirements for on-site treatment/disposal are not significant, no cost allowance is applied.

2) Where on-site land requirements are significant and the storage or disposal of wastes does not affect the ultimate market value of the land, cost estimates include only interest on invested money.

3) For significant on-site land requirements where the ultimate market value and/or availability of the land has been seriously reduced, cost estimates include both capital depreciation and interest on invested money.

4) Off-site treatment/disposal land requirements and costs are not considered directly. It is assumed that land costs are included in the overall contractor's fees along with its other expenses and profit.

5) In view of the extreme variability of land costs, adjustments have been made for individual industry situations. In general, isolated, plentiful land has been costed at $2,470/hectare ($1,000/acre).

Annual costs of operating the treatment/disposal facilities include labor, supervision, materials, maintenance, taxes, insurance, power and energy. Operating costs combined with annualized capital costs equal the total costs for treatment and disposal. No interest cost was included for operating (working) capital. Since working capital might be assumed to be one sixth to one third of annual operating costs (excluding depreciation), about 1-2 percent of total operating costs might be involved. This is considered to be well within the accuracy of the estimates.

The Development Document estimated treatment costs for a single representative facility at four levels of treatment. In this case, a typical wet crushed stone operation was assumed to produce 180,000 kkg/yr (200,000 tons/yr), half of which is washed, and half is dry processed. The assumed wash water usage is 1,000 l/kkg (240 gal/ton), and the assumed waste content is 6% of the raw material.

Levels of treatment evaluated include:

A - direct discharge
B - settling pond, discharge
C - settling pond, recycle
D - flocculation, settling pond, recycle.

In levels B and C, the waste water is passed through a one acre settling pond and discharged or recycled back to the facility. The pond is dredged periodically and the sludge is deposited on site.

Level D involves settling with flocculents and recycle. The waste water is treated with a flocculent and passed through a one acre settling pond. The effluent is then recycled. However, it is rare that a flocculent would be needed to produce an effluent quality acceptable for recycle in a crushed stone operation.

Unit costs used in this analysis were as follows:

Level B

Pond Cost	$10,000
Pumps and piping	4,500
Power	1,000
Pond cleaning	6,000
Taxes and insurance	400

Level C

Total pond cost	$10,000
Total pump and piping cost	9,000
Annual capital recovery	3,100
Power	2,000
Pond cleaning	6,000
Taxes and insurance	400

Level D

Additional capital flocculent equipment	$ 3,500
Additional annual capital	600
Annual chemical cost	1,000

It should be noted here that the value for power associated with pumping can vary widely depending on the topography of the site. In areas of high relief, the cost of pumping for recycle may be prohibitive.

The Development Document estimated capital cost, operating and maintenance costs and energy costs. These were presented separately as total annual cost and as cost/kkg of product. A subsequent study updated the values in the Document to mid-1974 dollars and expanded the analysis to include three additional plant sizes: 91,000 metric tons/year, 1,270,000 metric tons/year and 2,180,000 metric tons/year. The costs shown in the Development Document were modified in the Economic Analysis of Effluent Guidelines by using a GNP inflator of 16.5% (Reference EPA, 1977). Fixed capital costs were varied by the ratios of annual production costs raised to the 0.9 power, based on the 182,000 metric tons/year model plant size in the Development Document. Operating costs were varied as a direct function of plant capacity.

Tables 8-1 through 8-4 present the treatment costs for the four plant sizes. These costs were updated to 1978 dollars using a GNP deflator from 1974 to 1978 of 1.308.

As the tables indicate, treatment costs per ton of product vary only slightly with plant capacity. Allowing discharge from sedimentation ponds as opposed to requiring recycle would save the operator $0.028/ton wet process while causing no significant increase in suspended solids load. During the time EPA regulations requiring recycle were promulgated, no quarries were known to have closed due to prohibitive wastewater treatment costs. However, in many instances, costs for treatment were much higher than EPA estimates (NCSA, 1980). The average cost for treatment with a settling pond only is $0.167/ton wet process. If flocculation is required, costs will increase approximately $0.026/ton wet process. The majority of this cost is expected to be passed on to the consumer.

TABLE 8-I. PROCESS WATER COMPLIANCE COST FOR MODEL WET PROCESS Crushed Stone Facility

Plant Size: 91,000 Total (45,500 Wet) Metric Tons Per Year of Product

Plant Age: 40 Years

Base Year: 1978

Plant Location: Rural Location Near Population Center

	Level A	Level B	Level C	Level D
Invested Capital Costs:				
Total	0	11,910	15,700	18,580
Annual Capital Recovery	0	1,830	2,360	2,880
Operating and Maintenance Costs:				
Annual O & M (excluding power and energy)	0	4,970	4,970	5,630
Annual energy and power	0	780	1,570	1,570
Total Annual Costs	0	7,580	8,900	10,080
Cost/Metric Ton/Wet Process	0	0.167	0.196	0.222

Level Description:

A - direct discharge
B - settling pond, discharge
C - settling pond, recycle
D - flocculent, settling pond, recycle

TABLE 8-2. PROCESS WATER COMPLIANCE COST FOR MODEL WET PROCESS Crushed Stone Facility

Plant Size: 180,000 Total (90,000 Wet) Metric Tons Per Year of Product
Plant Location: Rural Location Near Population Center
Plant Age: 40 Years
Base Year: 1978

	Level A	Level B	Level C	Level D
Invested Capital Costs:				
Total	0	22,110	28,920	34,280
Annual Capital Recovery	0	3,660	4,710	5,630
Operating and Maintenance Costs:				
Annual O & M (excluding power and energy)	0	9,810	9,810	11,250
Annual energy and power	0	1,570	3,010	3,010
Total Annual Costs	0	15,050	17,530	19,890
Cost/Metric Ton/Wet Process	0	0.167	0.194	0.220

Level Description:

A - direct discharge
B - settling pond, discharge
C - settling pond, recycle
D - flocculent, settling pond, recycle

TABLE 8-3. PROCESS WATER COMPLIANCE COST FOR MODEL WET PROCESS Crushed Stone Facility

Plant Size: 1,270,000 Total Metric Tons Per Year of Product
(635,000 Wet)

Plant Location: Rural Location Near Population Center

Plant Age: 40 Years

Base Year: 1978

	Level A	Level B	Level C	Level D
Invested Capital Costs:				
Total	0	128,230	167,880	198,890
Annual Capital Recovery	0	25,910	33,240	39,650
Operating and Maintenance Costs:				
Annual O & M (excluding power and energy)	0	69,220	69,220	79,430
Annual energy and power	0	11,120	21,200	21,200
Total Annual Costs	0	106,250	123,660	140,280
Cost/Metric Ton/Wet Process	0	0.167	0.195	0.221

Level Description:

A - direct discharge
B - settling pond, discharge
C - settling pond, recycle
D - flocculent, settling pond, recycle

TABLE 8-4. PROCESS WATER COMPLIANCE COST FOR MODEL WET PROCESS Crushed Stone Facility

Plant Size: 2,130,000 Total Metric Tons Per Year of Product
(1,076,000 Wet)
Plant Location: Rural Location Near Population Center
Plant Age: 40 Years
Base Year: 1978

	Level A	Level B	Level C	Level D
Invested Capital Costs:				
Total	0	208,710	272,950	323,592
Annual Capital Recovery	0	34,540	44,489	53,125
Operating and Maintenance Costs:				
Annual O & M (excluding power and energy)	0	118,810	118,810	136,350
Annual energy and power	0	18,970	36,510	36,510
Total Annual Costs	0	172,320	199,810	225,980
Cost/Metric Ton/Wet Process	0	0.161	0.187	0.212

Level Description:

A - direct discharge
B - settling pond, discharge
C - settling pond, recycle
D - flocculent, settling pond, recycle

9.0 REFERENCES

1. American Public Health Association, American Water Works Association, and Water Pollution Control Federation, Standard Methods for the Examination of Water and Wastewater, Fourteenth Edition, 1976.

2. Bachmann, R. W., The Ecology of Four North Idaho Trout Streams with Reference to the Influence of Forest Road Construction. M.S. Thesis University of Idaho, 97 pp (unpublished) 1958.

3. Benoit, R. J., Cairns, J., Jr.; and Reimer, C. W. A Limnological Reconnaissance of an Impoundment Receiving Heavy Metals with Special Emphasis on Diatoms and Fish. Proceedings of Symposium on Res. Fish. Resources; American Fisheries Soc. 1968.

4. Bourelly, P., Les algues d'eau douce: I Algues vertes, 1966, 511 pp.; II. Les algues jaunes et brunes, 1968, 438 pp.; Algues bleues et rouges, 1970, 512 pp. North Boubeé, Paris.

5. Brashier, C. K., et al, "Effect of Silt and Silt Removal in a Prairie Lake," EPA-R3-73-037, prepared for the office of Research and Monitoring, U. S. EPA, 1973.

6. Brown, Harley P., Biota of Freshwater Ecosystems. Identification Manual No. 6 Aquatic Dryopoid Beetles (Coleoptera) of the United States; Smithsonian Institution, 1972.

7. Buck, D. H., Effects of Turbidity on Fish and Fishing. Trans. North American Wildlife Conference 21; pp. 249-261, 1956.

8. Burch, J. B., Biota of Freshwater Ecosystems. Identification Manual No. 3 Freshwater Sphaeriacean clams (Mollusca: Pelecyopda) of North America. Smithsonian Institution, 1972.

9. Burch, J. B., Biota of Freshwater Ecosystems. Identification Manual No. 11 Freshwater Unionaceon Clams (Mollusca: Pelecypoda) of North America, Smithsonian Institution, 1973.

10. Burris, John W. and Cooper, Charles M., "The Influence of Turbidity on Planktonic and Benthic Organisms," Proceedings of the Mississippi Water Resources Conference, Water Resources Institute, pp. 87-96, 1977.

11. Cairns, John, Jr., "Suspended Solids Standards for the Protection of Aquatic Organisms," Engineering Bulletin, Purdue University, Engineering Extension Series 129 (1), pp. 16-27, 1968.

12. Campbell, H. J., "The Effect of Siltation from Gold Dredging on the Survival of Rainbow Trout and Eyed Eggs in Powder River, Oregon," Oregon State Game Commission, 3 pp., 1954.

13. Casey, O. E., The Effects of Placer Mining on a Trout Stream. Annual Progress Report, Project F34-R-1. Water Quality Investigation.Federal Aid in Fishery Restoration, Idaho Department of Fish and Game, pp. 20-27, 1959.

14. Chapman, V. J., 1962. The Algae. Macmillan, London. 472 pp.

15. Chutter, F. M., "The Effects of Silt and Sand on the Invertebrate Fauna of Streams and Rivers," Hydrobiologia 34, pp. 57-76, 1969.

16. Cordone, A. J., and Pennoyer, S., Notes on Silt Pollution in the Truckee River Drainage. California Department of Fish and Game, Inland Fishery Administration Report. 60-14, pp. 25, 1960.

17. Cordone, A. J. and Kelley, D. W., "The Influence of Inorganic Sediment on the Aquatic Life of Streams," California Department of Fish and Game 47 (2): pp. 189-228, 1961.

18. Council on Environmental Quality, 1979, Environmental Statistics, 1978, Cosponsored by U. S. Geological Survey and U. S. Environmental Protection Agency.

19. Delfino, J. J., "Effects of River Discharge and Suspended Sediment on Water Quality in the Mississippi River," Journal of Environmental Science and Health, 1977.

20. Douglas, Neil H., Freshwater Fishes of Louisiana. Claitor Publishing, Baton Rouge, La, 1974.

21. Eddy S. and Surber, T., Northern Fishes. Branford and Co. Newton, Mass., 2nd Edition, 1960.

22. Ellis, M. M., Some Factors Affecting the Replacement of the Commercial Fresh-water Mussels. U. S. Department of Commerce, Bureau of Fish and Fisheries; Circular 7, 1931.

23. Ellis, M. M., "Erosion Silt as a Factor in Aquatic Environments," Ecology. Vol. 17, No. 1, pp. 29-42, Jan., 1936.

24. Ellis, M. M., Water Purity Standards for Freshwater Fishes. U. S. Fish and Wildlife Service. Special Scientific Report No. 2: 16, 1944.

25. Environmental Protection Agency, Development Document for Interim Final Effluent Limitations Guidelines and New Source Performance Standards for the Mineral Mining and Processing Industry, June 1976.

26. Environmental Protection Agency, Office of Water and Hazardous Materials, Quality Criteria for Water, pp. 256, 1977.

27. Environmental Protection Agency, Office of Water Planning and Standards, Economic Analysis of Effluent Guidelines, Mineral Mining and Processing Industry, May 1977.

28. Environmental Protection Agency, "Water Quality Criteria, Request for Comments," Federal Register Vol. 44, No. 191, pp. 56632-35, 1 October 1979.

29.European Inland Fisheries Advisory Commission (EIFAC), Water Quality Criteria for European Freshwater Fish. Report on Finely Divided Solids and Inland Fisheries. EIFAC Technical paper No. 1, International Journal of Air and Water Pollution 9; pp. 151-168, 1965.

30. Ferris, V. R., et al., Biota of Freshwater Ecosystems. Identification Manual No. 10. Genera of Freshwater Nematodes (Nematoda) of Eastern North America, Smithsonian Institution, 1973.

31. Foster, Nancy, Biota of Freshwater Ecosystems. Identification Manual No. 4. Freshwater Polychaetes (Annelida) of North America. Smithsonian Institution, 1972.

32. Gammon, J. R., "The Effects of Inorganic Sediment on Stream Biota," Water Pollution Control Resource Service 18050 DWC, U. S. EPA; U. S. Government Printing Office, Washington, DC, Dec. 1970.

33. Griffin, L. E., "Experiments on the Tolerance of Young Trout and Salmon for Suspended Sediment in Water," Bulletin, Oregon Department of Geology (10), Appendix B: pp. 28-31, 1938.

34. Harlan, J. R. and Speaker, E. B., Iowa Fish and Fishing. Iowa State Conservation Commission. Dubuque, Iowa, 1951.

35. Harrison, C. W., Planting Eyed Salmon and Trout Eggs. American Fishery Society Transactions 53: pp. 191-200, 1923.

36. Hastings, C. E. and Cross, F. B., Farm Ponds in Douglas County Kansas, University of Kansas, Museum of Natural History, Miscellaneous Publication 29; pp. 1-21, 1962.

37. Heimstraw, N. W., Damkot, D. K., and Benson, N. G., Some Effects of Silt Turbidity on Behavior of Juvenile Largemouth Bass and Green Sunfish. U. S. Bureau of Sport Fish and Wildlife, Tech. Paper 20: 9 pp.

38. Herbert, D. W. M. and Merkens, J. C., "The Effects of Suspended Mineral Solids on the Survival of Trout," International Journal of Air and Water Pollution 5: pp. 46-55, 1961.

39. Herbert, D. M. W. and Richards, J. M., "The Growth and Survival of Fish in Some Suspensions of Solids of Industrial Origin," Internation Journal of Air and Water Pollution, 7: pp. 297-302, 1963.

40. Hobbs, D. F., Natural Reproduction of Grummat Salmon, Brown and Rainbow Trout in Certain New Zealand Waters. New Zealand Mar. Department of Fisheries Bulletin 6: pp. 104, 1937.

41. Hobbs, Horton H., Biota of Freshwater Ecosystems. Identification Manual No. 9. Crayfishes (Astacidae) of North and Middle America. Smithsonian Institution, 1972.

42. Holsenger, John R., Biota of Freshwater Ecosystems. Identification Manual No. 5. The Freshwater Amphipod Crustaceans (Gammaridae) of North America, Smithsonian Institution, 1972.

43. Howland, J. W., Studies on the Life History of the Spotted or Kentucky Bass, *Micropterus Pseudoplites* Hubles. Ph.D. dissertation, Ohio State Univ., 1931.

44. Hubbell, P. M., Warmouth: in Inland Fisheries Mgt. A Calhoun (ed.) California Department of Fish and Game, pp. 405-407, 1966.

45. Huck, L. L. and Gunning, G. E., Behavior of the Longear Sunfish, *Lepomis magalotis* (Rafinesque). Tulane Studies in Zoology. 14 (3): pp. 121-131, 1967

46. Hunsaker, D. Jr., and Crawford, R. W., Preferential Spawning Behavior of the Largemouth Bass, *Micropterus salmoides*. Copeia 1: pp. 240-241, 1964.

47. Hutchinson, G. E., A Treatise on Limnology, Volume VIII Limnological Botany, John Wiley and Sons, 1975.

48. Kahle, Katherine, Unpublished report. Dept. of Civil Engineering, Stanford University, 1980.

49. Kenk, Roman, Biota of Freshwater Ecosystems. Identification Manual No. 1 Freshwater Planarians (Turbellaria) of North America. Smithsonian Institution, 1972.

50. King, D. L. and Ball, R. C., The Influence of Highway Construction on a Stream. Research Report, Michigan State University, Agricultural Experiment Station, Nov. 19, 1964.

51. Klages, M. G. and Adamsem, F. J., "Effects of Suspended Silt on Dissolved Phosphorus Level in the Gallatin River," Montana University Joint Water Resources Research Center, August 1974.

52. Klemm, Donald J., Biota of Freshwater Ecosystems. Identification Manual No. 8 Freshwater Leeches (Annelida: Hirudinea) of North America. Smithsonian Institution, 1972.

53. Kuschner, Marvin, et al, "Does the Use of Asbestos-cement Pipe for Potable Water Systems Constitute a Health Hazard?" The Journal of the American Water Works Association Committee Report, September 1974.

54. Larimore, R. W., Ecological Life-history of the Warmouth (Centrarchidae). Illinois Natural History Survey Bulletin 27(1): pp. 1-83, 1957.

55. McClane, A. J., Field Guide to Freshwater Fishes of North America. Holt, Rinehart, and Winston, 1978.

56. McWilliam, Lilia M.; Stout, Roy G.; Willey, Benjamin F., "Asbestos in Raw and Treated Water: An Electron Microscopy Study," Environmental Science and Technology, Vol. 11, No. 4, pp. 390-400, 1977.

57. Metcalf and Eddy, Inc., Wastewater Engineering Treatment Disposal Reuse, Second Edition, McGraw-Hill, 1979.

58. Morgan, G. D., The Life History of the White Crappie *(Pomoxis annularis)* of Buckeye Lake, Ohio Journal of Science, Denison University 43, (6,7,8): pp. 113-144, 1954.

59. Morgan, G. D., A Study of Six Different Pond Stocking Ratios of Largemouth Bass, *Micropterus salmoides* (Lacepede), and Bluegill, *Lepomis macrochirus* Rafinesque, and the Relation of the Chemical, Physical, and Biological Data to Pond Balance and Productivity. Journal of Science, Denison University 44: pp. 151-202, 1958.

60. Moyle, J. B., Some Chemical Factors Influencing the Distribution of Aquatic Plants in Minnesota. American Midland Naturalist 34: pp. 402-420, 1945.

61. Mraz, D.; Kmiotek, S.; and Frankenberger, L., The Largemouth Bass; Its Life History, Ecology and Management. Wisconsin Conservation Department Publication 232, 1961.

62. National Academy of Science, National Academy of Engineering. Water Quality Criteria, 1972. A report of the Committee on Water Quality at the request and funded by the Environmental Protection Agency, 1972.

63. National Academy of Sciences, National Academy of Engineering. Water Quality Criteria, 1972. EPA Ecological Research Series, EPA-R3-73-033 U. S. EPA, Washington, pp. 594, 1973.

64. National Crushed Stone Association, Rick Renniger, April 1980.

65. Needham, J. G., and Needham, Paul A., A Guide to the Study of Freshwater Biology. Holden-Day, Inc., San Francisco, 1962.

66. Olson, Harold L., "Asbestos in Potable Water Supplies," Journal of American Water Works Association, Vol. 66, No. 9, pp. 515-518, 1974.

67. Patrick, R., and Reimer, C. W., The Diatoms of the United States, Vol. 1, Academy of Natural Sciences of Philadelphia, 1966.

68. Pennak, Robert W., Freshwater Invertebrates of the United States, Ronald Press, New York, 1979.

69. Portland Cement Association, Telephone Communications, April 1980.

70. Prescott, G. W., How to Know the Fresh-water Algae. Brown, Dubuque, Iowa, 1970.

71. Raney, E. C., Some Panfishes of New York, Rock Bass, Crappies and Other Sunfishes. New York State Conservation Department Information Leaflet D-47, pp. 10-16, 1965.

72. Robertson, M., The Effects of Suspended Materials on the Reproductive Rate of *Daphnia magna*. Publication Institute Marine Sciences, University of Texas 4, pp. 265-277, 1957.

73. Robinson, A. R., "Sediment, Our Greatest Pollution," Agricultural Engineering, August 1971.

74. Robinson, D. W., Utilization of Spawning Box by Bass. Progress in Fish Culture 23(3): pp. 119, 1961.

75. Schubel, J. R.; Auld, A. H., and Schmidt, Effects of Suspended Sediments on the Development and Hatching Success of Yellow Perch and Striped Bass Eggs. J. Hopkins University, Chesapeake Bay Institute, Special Report 35, 1974.

76. Shiveman, J. V., Age and Growth of Bluegills, *Lepomis macrochirus* Rafinesque, from Selected Central Iowa Farm Ponds. Iowa Academy of Science 75: pp. 170-178, 1968.

77. Smith, G. M., Freshwater Algae of the United States. McGraw-Hill, New York, 1950.

78. Smith, L. L. and Moyle, J. B., A Biological Survey and Fishery Management Plan for the Streams of the Lake Superior North Shore Watershed. Minnesota Department of Conservation, Division of Game and Fish, Technical Bulletin 1: pp. 228, 1944.

79. Smith, L. L., Jr.; Kramer, R. H., and MacLeod, J. C., "Effects of Pulpwood Fibers on Fathead Minnows and Walleye Fingerlings. Journal of Water Pollution Control Federation 37: pp. 130-140, 1965.

80. Smith, O. R., Placer Mining Silt and its Relation to Salmon and Trout on the Pacific Coast. Transactions of the American Fishery Society 69: pp. 225-230, 1940.

81. Stephan, H.; Seefischerei und Hochwasser. (Der Einfluss von anorganischen Schwebestoffen auf Cladoceren und Copepoden) Dissertation, Naturw, Fakutät, München, 1953.

82. Suber, E. W., Observations on the Natural and Artificial Propagation of the Smallmouth Black Bass, *Micropterus dolomieu*. Transactions of the American Fishery Society 72: pp. 233-245.

83. Tarzewell, C. M., Water Quality Criteria for Aquatic Life; in Transactions of Seminar on Biological Problems in Water Pollution; Robert A. Taft Sanitary Engineering Center, Cincinnati, Ohio, U. S. Dept. HEW, 1957.

84. Trautman, M. B., The Fishes of Ohio. Ohio State University Press, 1957.

85. Turner, G. E. and MacCrimmon, H. R., Reproduction and Growth of Smallmouth Bass, *Micropterus dolomieui*, in a Precambrian Lake. Journal of Fishery Resource Board, Canada 27(2): pp. 395-400, 1970.

86. University of Pittsburg, Graduate Center for Public Works Administration, The Effects of Strip Mining Upon Navigable Water and Their Tributaries: Discussion and Selected Bibliography, For the Department of the Army, 1972.

87. Vivier, P., Water Quality Criteria for European Freshwater Fish, p. 160, EIFAC, 1965.

88. Walberg, C. H., Fish Population Studies, Lewis and Clark Lake, Missouri River, 1956-1962. U. S. Fish and Wildlife Service, Special Scientific Report 482: pp. 1-27, 1964.

89. Wallen, Eugene I., "The Direct Effect of Turbidity on Fishes," Oklahoma A&M College, Arts and Sciences Studies, Biological Series, No. 2, Bulletin 48(2): pp. 1-27, 1951.

90. Westlake, D. F., The Light Climate for Plants in Rivers; In: Light as an Ecological Factor. (G.C. Evans, R. Bainbridge and O. Rackham eds.) British Ecological Society Symposium No. 6: pp. 99-120, Blackwell Sciences Publications, 1966.

91. Williams, W. D., Biota of Freshwater Ecosystems. Identification Manual No. 7. Freshwater Isopods (Asellidae) of North America, Smithsonian Institution, 1972.

92. Wilson, J. N., Effects of Turbidity and Silt on Aquatic Life; In Biological Problems in Water Pollution. U. S. Dept. HEW Robert A. Taft Sanitary Engineering Center, pp. 235-239, 1957.

93. Wolf, P. H., American Problems and Practice I. Salmon Which Dissappeared. Salmon and Trout Magazine, 130: pp. 201-212, 1950.

94. Ziebell, C. D. and Knox, S. K., Turbidity and Siltation Studies, Wynooche River. Report to Washington Pollution Control Commission, pp. 7, 1957.

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